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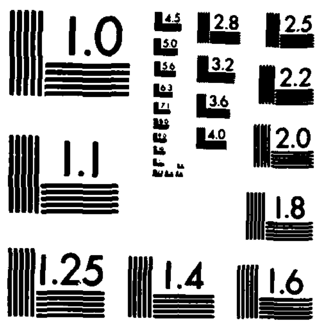

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TITLE: RELIABILITY, AVAILABILITY, AND MAINTAINABILITY OF THE HEAT RECOVERY INCINERATOR AT NAVAL STATION MAYPORT

AUTHOR: J. Zimmerle

DATE: October 1984

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PROGRAM NO: YO817-006-01-211

NOTE

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

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METRIC CONVERSION FACTORS

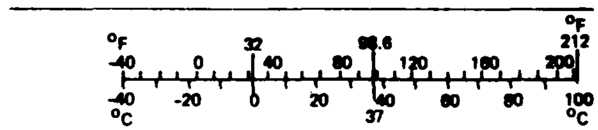
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The heat recovery incinerator (HRI) at Naval Station Mayport, Fla. was studied to determine the expected long-term performance of the HRI. The data, which were collected from October 1980 to August 1983, were analyzed for reliability, availability, maintainability, waste incineration rate, thermal efficiency, and steam cost. Actual results for incinerating waste to produce steam were: reliability 58% (75% of design); availability 82% (91% of goal); maintainability 0.10 man-hr/ton (100% of goal); thermal

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20. Continued

efficiency 48% (87% of goal); incineration rate 1.75 tons/hr (105% of goal); and cost of steam $6.05/MBtu. The HRI was expected to save $26,600/yr from landfill reductions and $102,320/yr from energy savings.

The principal reasons for the shortfalls in performance were shortages of solid waste, and failures in the crane, feed rams, ash conveyor, front-end loader, feedwater equipment, and induced draft (I.D.) fan. Corrections have been made in HRI operation to improve performance of the ash conveyor. Recommendations are made on additional maintenance procedures, and on equipment design criteria to improve plant operation and for future plant design.

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CONTENTS

INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC) tasked the Naval Civil Engineering Laboratory (NCEL) to evaluate heat recovery incinerator (HRI) technology for application at Naval shore activities. As part of this project, NCEL studied the long-term performance of the mass burning HRI at Naval Station (NS) Mayport, Fla. The reliability, availability, and maintainability (RAM) study was conducted to determine any changes necessary to improve the existing HRI and to provide guidance for future HRIs of this type.

BACKGROUND

Heat recovery incineration is a developing technique for converting the combustible portion of solid waste into usable energy through the production of steam. The economic benefits achievable from using HRI technology are dependent on the savings obtained from reducing fossil fuel use and from reducing the quantity of solid waste that must be disposed.

The Navy has 591 installations worldwide (Ref 1) which generate an estimated 1.7 million tons of solid waste per year, of which approximately 85% is combustible (Ref 2). If this waste were incinerated to recover energy, 8,300,000 MBtu, or 1.4 million barrels of oil equivalent (BOE), would be available to offset fossil fuel utilization.

The Navy paid $9.27/MBtu of steam in 1982 (Ref 3). Collection and disposal costs for solid waste averaged $34/ton in 1982 ($18/ton to collect, $16/ton to dispose), and the costs may double within the next 10 years because of limited landfill space and legislative restrictions (Ref 4).

RAM analyses are used to mathematically predict or verify the performance of an equipment system. The application of RAM study techniques to the NS Mayport HRI was one of the first uses of RAM parameters to evaluate HRI technology. RAM studies are based on data for operating time and maintenance actions (failures and other actions). Operating time is the total time the HRI, subsystem, or mission is functional. Maintenance actions are equal to the total number of failures and other actions. Failures are defined as any event that causes the HRI, subsystem, or a mission to be shutdown and requires a part repair or replacement. Other actions are those events that cause a shutdown, but occur due to the need to adjust, calibrate, or unjam a piece of equipment. The three RAM parameters studied are reliability, availability, and maintainability. These parameters are expressed mathematically as Equations A-7 through A-16 in Appendix A.

Reliability is expressed as the probability that an equipment system can complete a specified operational cycle without a failure occurring. Reliability is useful as an indicator of inadequate or degrading performance. In general, following installation and a shakedown phase, reliability should reach a steady state value and then decay due to equipment aging. This decay is used to predict equipment replacement time or to indicate when repairs or adjustments are needed. Changes in design are indicated if steady state values never reach acceptable values.

Availability is expressed as the probability that at any point in time the system will be capable of performing its stated mission. Availability is a measure of the length of time that a system will be able to perform a given task under its mission. A low availability value means that adjustments or repairs are needed or that design changes are required. Availability decays in a similar fashion to reliability.

Maintainability is expressed as the total number of maintenance man-hours required for every hour of operating time. Maintainability is an indication of the level of effort required to keep the system operational. A large value for maintainability means that maintenance is too complex, equipment is too old, or maintenance access to equipment is inadequate. In general, maintenance increases as equipment ages because more failures occur and more adjustments are necessary to maintain performance levels.

HRI AT MAYPORT

The HRI at NS Mayport was installed at a cost of $2.3 million. Installation was completed in March 1979, operation began in December 1979, and testing began in September 1980. The facility, which is depicted in Figures 1 and 2, and consists of receiving, incineration, boiler, and ash subsystems.

Description of Subsystem

The HRI was designed to operate in the following manner:

Receiving Subsystem. The collected waste is deposited on the tipping floor, where it is manually sorted to remove large metals; bulky dangerous items; and other materials that would interfere with HRI operation. After sorting, a front-end loader pushes the waste into a storage pit. The pit was designed to store approximately 1 day of solid waste deliveries to reduce the effects of quantity variation and HRI downtime. A 1-1/2-ton-capacity overhead crane removes the waste from the storage pit and places it into the incinerator feed hopper.

Incineration Subsystem. The incineration subsystem was designed by Washburn and Granger to burn waste at a maximum rate of 2 tons/hr (TPH). The waste from the feed hopper is pushed onto the hearth of the primary combustion chamber by a hydraulic ram where it is combusted at 1,400 to 1,600°F, releasing gases and turning the waste into an inert ash. The gases enter the secondary combustion chamber where the remaining combustible matter is incinerated at 1,600°F.

Boiler Subsystem. The hot gases enter the boiler subsystem and pass through a single-pass fire tube boiler that recovers the energy as steam. Finally, the cooled gases are discharged to the atmosphere after passing through a multicyclone separator to remove particulates.

Ash Subsystem. The inert ash is mechanically removed from the primary combustion chamber by stoker grates to the ash subsystem. The grates move the waste through the chamber in order to mix the waste and allow a more thorough carbon burnout as the waste turns to ash. The ash drops to a water quench tank to be cooled and is then removed by a drag chain to a container. The ash container is periodically dumped at the local landfill.

Operational Objectives

The HRI was designed to accomplish two objectives. The primary objective of the HRI was to extend the life of the local landfill by reducing the volume and weight of the solid waste through incineration. The secondary objective of the HRI was to produce low pressure steam for the activity without burning fossil fuels. This would be accomplished by recovering energy from the combustion products of the incinerated solid waste. These objectives represent the two benefit-producing functions of the HRI: landfill savings and fossil fuel offsets.

The HRI is in one of three modes or missions when it is operational (Figure 3). These missions represent the various combinations of accomplishing the two design objectives. A numerical subscript on the results signifies which mission is represented (i.e., R_1 is the reliability for Mission 1).

Mission 1. The first mission is to incinerate solid waste to produce steam. Each of the four subsystems is operational to perform this mission. This mission is the preferred operating mode for the HRI as both benefit functions - landfill savings, and fossil fuel offsets - are being accomplished.

The HRI was expected to operate under Mission 1 with a mean time between failures (MTBF) of 446 hours; in other words, 14 failures per year were anticipated (Ref 5). Mission 1 RAM performance of the HRI was predicted to be: reliability of 77%, availability of 90%, and maintainability of 0.1 man-hr/ton of waste incinerated (or 0.2 man-hr/operating-hr). These expectations and goals were documented after HRI construction, and were based on technological assessment of installed equipment and components (Ref 5 and 6).

Mission 2. The second mission is to only incinerate solid waste. This mission requires that all the subsystems be operational except for the boiler subsystem. Mission 2 serves as the backup mission to the primary objective of the HRI in the event the boiler cannot operate; the benefit is the landfill savings.

The expected HRI performance under Mission 2 was better than Mission 1 parameters because fewer subsystems would be operational. The predicted MTBF was 693 hours or nine failures per year (Appendix B). This corresponds to a reliability of 84%. The Mission 2 value for availability was predicted to be 90%. Mission 2 maintainability was not determined because maintenance data were only collected for Mission 1 performance.

Mission 3. The third mission is to produce steam through the use of fuel oil or waste oil. For this mission only the incinerator (not including stoker grates and tuyeres) and the boiler subsystems must be operational. Mission 3 is the backup mission to the secondary objective of the HRI in the event no solid waste is available. The benefit of this mission is the production of steam when no solid waste is available, or the HRI cannot incinerate waste. Fossil fuel offsets occur if waste oil is used to produce steam.

The expected HRI performance under Mission 3 was better than Mission 1 or 2 parameters because fewer subsystems would be operational. The predicted MTBF was 891 hours, or seven failures per year (Appendix B). The expected reliability was calculated as 88%. The corresponding value for availability was predicted to be 90%. Mission 3 maintainability was not determined because maintenance data were not available.

Operational Parameters

Nine additional parameters are considered important in judging HRI performance. These parameters are waste generation rate, incineration rate, ash production, landfill reduction and cost savings, steam production, annual steam cost, fossil fuel offsets/thermal efficiency, incineration time, and maintenance man-hours. These parameters were used to define the predicted performance and logistics required to utilize the HRI and to determine changes in the areas of planning, design, and maintenance that would improve future HRI performance.

Activity Waste Generation Rate. The activity waste generation rate is expressed as an average solid waste quantity produced by the activity in tons per day (TPD). This parameter was used in the design and economic feasibility assessment of the HRI. The activity was predicted to generate 40 TPD (Ref 7).

Incineration Rate. The incineration rate is expressed as tons of solid waste incinerated per hour (TPH). This parameter is a design value based on the quantity of waste generated by the activity. For this HRI, the design value was a maximum 2 TPH (Ref 7) with an average 1.67 TPH based on 40-TPD design.

Ash Production. Ash production is measured as tons of ash (wet and fly) produced per hour of incineration. This parameter is a performance value based on the ash content of the incinerator-fed solid waste and the effectiveness of the incineration process. The predicted value was 0.6 ton of ash per hour of incineration (0.3 ton/ton of waste) (Ref 6) based on a 2-TPH incineration rate.

Landfill Reduction and Cost Savings. Landfill reduction is a measure of HRI effectiveness in completing the primary task of the HRI. The parameter is expressed as a percentage decrease in the quantity of waste landfilled. Landfill reduction is used to determine the annual cost savings from incinerating the waste. The expected value was 70% of the waste accepted by the facility would be destroyed (Ref 6) with a maximum disposal cost savings of $51,000/yr (200 ton/wk at $7/ton).

Steam Production. Steam production is measured as pounds of steam produced per hour of incinerator operation. This parameter is a performance value related to the thermal efficiency of the HRI, the quantity of waste and oil incinerated, and the potential fossil fuel offsets. The expected value was 10,000 lb/hr based on 6,000 pounds of steam per ton of waste (Ref 6) and a 1.67-TPH incineration rate.

Average Steam Cost. Average steam cost is expressed as the cost in dollars of producing 1 MBtu of steam. Any operation, maintenance, or consumable costs involved in steam production are included in this parameter. This parameter is a performance value and is related to the labor and consumable usage of the HRI. The HRI steam cost was $8.70/MBtu in 1983 at NAS Jacksonville (Ref 8), which had similar boiler costs to NS Mayport. The $8.70/MBtu value compares favorably to the average Navy cost of purchased steam, which was $9.27/MBtu in 1982 (Ref 3).

Fossil Fuel Offsets/Thermal Efficiency. Fossil fuel offsets are a measure of the effectiveness of completing the secondary task of the HRI. The offsets are expressed as the total BOE saved by producing steam from the solid waste. This parameter is a performance value based on the thermal efficiency and the quantity of waste and oil incinerated. The expected fossil fuel offset value was predicted to be 240 BOE/week based on incinerating 200 ton/wk.

Thermal efficiency is expressed as a percentage that represents the effectiveness of the energy conversion process. The parameter is based on the effectiveness of the incinerator and boiler operations. The design value for thermal efficiency was 55% (Ref 6).

Incineration Time. Incineration time is measured as the average time the HRI is burning solid waste. This parameter is related to availability and represents the incineration time that can be sustained by the HRI. The parameter is expressed as hours of operating time per week for incinerating solid waste or burning fuel oil. The design value was 120 hr/wk for a 5-day week (Ref 6).

Maintenance Man-hours. Maintenance man-hours are a function of the level of effort required to keep the HRI operational. The parameters are logistics values which are expressed as the number of preventive maintenance man-hours per week of operation, and corrective maintenance as mean time to repair (MTTR) in hours per failure. The parameters are related to the operating cost and performance of the HRI. The expected values were 15 man-hr/wk scheduled for two personnel over the weekend shutdown, and 10 hours per failure.

Subsystem Operational Parameters

Each subsystem was designed to accomplish a different objective. The receiving subsystem was designed with a storage pit sized for 1 day of waste deliveries (40 tons) and a 2-TPH removal rate. The incinerator subsystem was designed to burn a maximum of 2 TPH of waste and produce 0.6 TPH of ash. The boiler subsystem was designed to produce a maximum of 10,500 pounds of steam/hour at an energy content of 1,185 Btu/lb.

The ash removal subsystem was designed to remove 0.6 TPH of ash from the quenchtank. Waste incineration would stop if the ash subsystem were down, to prevent ash buildup in the quenchtank.

TECHNICAL APPROACH

Data Collection

The data required to determine the various HRI parameters were reported on the seven datasheets (Ref 9) shown in Appendix C. The datasheets were prepared weekly by plant personnel and sent to NCEL for analysis. The data were collected from a series of meters, scales, and HRI records. Totalizing meters were used to record solid waste incinerated, induced draft (I.D.) fan run time, and electrical power, steam flow, waste oil, fuel oil, make-up water, and blowdown consumed. Scales were used to weigh loaded fly ash, wet ash, and reject containers. HRI records/datasheets were used to determine manpower and man-hours in operation and maintenance, and the type and cost of spare parts and consumables.

Datasheet 1 was filled out whenever the HRI was started or restarted (normally early on Monday). The type of data collected was the date and time of start-up and the initial meter readings for solid waste, I.D. fan run time, electrical power, steam flow, waste oil, fuel oil, make-up water, and blowdown. The first datasheet was used to establish the initial meter readings for the stated consumables and the weekly operation time.

Datasheet 2 was filled out once per week and was used to record the quantity of fly ash, rejects, and wet ash which were produced during the week. The second datasheet was used to determine the ash production and landfill reduction parameters for the HRI.

Datasheet 3 was filled out whenever the waste feed ram was shut off and completed whenever the ram was turned back on. The type of data collected was the date and time when the ram was turned on and off and the reason why the ram was turned off. The third datasheet was used to modify the operational parameters connected with the time categories during times when no waste was available or a nonboiler failure occurred. The specific time category the shutdown period was assigned to depended on the reason for the shutdown.

Datasheet 4 was filled out whenever the HRI was shutdown due to normal weekend shutdown on late Friday, holidays, or due to failures or maintenance actions. The type of data collected was the final meter readings for the consumable data on Datasheet 1, plus the reason for the shutdown, and the man-hours and the water treatment chemicals used between the period from Datasheet 1 to 4. The fourth datasheet was used to establish the final meter readings for the stated consumables, the weekly operational time, and the man-hours used to operate the HRI.

Datasheet 5 was normally filled out once per week when the scheduled routine maintenance was completed on the weekend. The type of data collected was the date and time when the maintenance was started and finished, the man-hours spent on maintenance, and the type of maintenance performed. The fifth datasheet was used to establish the routine maintenance parameters and regular procedures.

Datasheet 6 was filled out whenever a shutdown caused by a malfunction and/or a need to replace a component occurred. The type of data collected was the date and time when the repair started and was completed, the man-hours spent in repair, the type and cause of the breakdown, and the type and cost of spare parts and consumables used. The sixth datasheet was used to establish the corrective maintenance parameters and spare parts logistics.

Datasheet 7 was filled out for any shutdown which was not caused by a failure or part replacement. The data collected were the reasons for the shutdown. The seventh datasheet was used to establish the time category for the weekend idle time. This information was used in determining availability.

Raw Data Analysis

The raw data were divided into six 6-month sections to facilitate analysis and to determine parameter trends. These data are listed in Table 1, with the analysis results in Table 2. The results from the first four 6-month sections were published in References 10 and 11. The results of the last two sections, from July 1982 to August 1983, are included in Appendix A as a detailed example of the analysis procedure.

The first step of the analysis procedure was to take the raw data from the datasheets and convert them into a useful form for parameter determination. The principal conversion categories were consumables, manpower, failures, other actions, and time.

The consumable raw data were determined from Datasheets 1 and 4. The final readings on Datasheet 4 were subtracted from the initial readings on Datasheet 1 to obtain the quantity of consumable used.

Manpower, failures, and other action data were taken directly from the datasheets. Manpower was found on Datasheet 4 for operation and on Datasheets 3, 5, and 6 for maintenance. Failure information was found on Datasheets 5 and 6. Datasheets 3 and 5 contained the information on maintenance actions (fixing jams or making adjustments). Datasheet 6 contained information on repairs, part replacement, and cost.

The five time categories were the most difficult to determine and were based on the time period between consecutive Datasheets 1. The basic operating time (t_a) was found by taking the time differential between Datasheets 1 and 4. Routine and corrective maintenance times were found by taking the time differential between maintenance start and finish for Datasheets 5 and 6, respectively. The remaining time in the period between each Datasheet 1 was placed into the idle time categories. Idle, but operational time (t_d) was used when the HRI could have been operated but was idle due to a nonfailure shutdown, such as the weekend shutdown. Idle, but not operational time (t_e) was used when the HRI could not be operated due to a failure or need for part replacement. The sum of the five time categories equaled the actual calendar time that occurred during the time period.

The equations for determining RAM parameters are listed as Equations A-1 to A-16 in Appendix A. The principal data required to determine RAM parameters were time, failure, and maintenance data. These data were found on Datasheets 1 and 3 through 7.

RAM parameters were determined for each of the three missions. These missions had different operating time categories, failures, and maintenance requirements. By analyzing the datasheets for these differences, the individual RAM parameters could be calculated. This type of analysis is detailed in Appendix A.

Mission Analysis

Mission 1. Operating time data were determined by examining the recorded start and stop times on Datasheets 1 and 4 minus any time the waste ram was turned off (Datasheet 3) or no steam was being produced (Datasheet 6 -- boiler failures). Routine and corrective maintenance times were calculated from Datasheets 3, 5, and 6. Idle, not operational time was any time segment the HRI could not accomplish Mission 1. Idle, but operational time was the remainder of the time period.

All the failures or other actions that occurred were used in RAM calculations (Datasheets 3, 5, and 6). This means that the Mission 1 RAM parameters had the lowest values of the three missions.

Mission 2. The time, failure, and maintenance data for Mission 2 RAM parameter calculations were the same as Mission 1 except for the following changes. Operating time (t_a) was increased because any failure involving the boiler subsystem did not affect Mission 2. The increase was equal to the corrective maintenance (t_c) and the idle, but not operational time (t_e) caused by the boiler failures. To maintain a one-to-one correspondence with real time, the t_c and t_e times were decreased by the respective quantities of time added to t_a.

The number of failures and other actions were also decreased by subtracting those items that occurred in the boiler subsystem. The same situation applied for any maintenance performed on the boiler subsystem. This effort was removed from Mission 2 calculations. The overall result of these changes was that the RAM parameters had better values than Mission 1.

Mission 3. The time, failure, and maintenance data for Mission 3 RAM parameters were the same as Mission 1 except for the following changes. Operating time was increased by adding any time steam was produced when no solid waste was available (t_d, Datasheet 3) and any time spent repairing receiving and ash subsystems, and stoker or tuyere failures in the incineration subsystem (t_c and t_e, Datasheets 5 and 6). As in Mission 2 analysis, time categories t_c, t_d, and t_e were decreased by the respective quantities added to t_a.

Any failures, other actions, or maintenance effort that occurred on the receiving and ash subsystems or due to stoker or tuyere failures in the incinerator subsystem were removed from the respective data categories. The overall result of these changes was that Mission 3 had the best RAM performance of the missions.

Operational Parameters Analyses

Activity waste generation rate was measured by taking the total solid waste incinerated from Datasheet 4 plus the total quantity of rejected waste from Datasheet 2 divided by the number of weeks both sets of data were reported.

Incineration rate was measured by dividing the total solid waste incinerated (Datasheet 4) by the incineration time in hours (Datasheets 1, 3, and 4), which is listed as Equation A-42 in Appendix A.

Ash production was measured by dividing the weight of ash produced (Datasheet 2) by the incineration time in hours (Datasheets 1, 3, and 4) or the tons incinerated (Datasheet 4).

Landfill reduction was calculated from Equation A-45 in Appendix A. The quantity of waste sent to the landfill was divided by the waste quantity received by the facility. The landfill waste was the total of wet ash, fly ash, and rejects listed in Datasheet 2. The quantity of received waste was on Datasheet 4. The cost reduction was equal to the quantity of waste received times the landfill reduction times $7/ton disposal fees.

Steam production was calculated using Equation A-43 in Appendix A. The steam produced from solid waste only was divided by the pounds of waste incinerated.

Average steam cost was calculated using Equations A-29 to A-41 in Appendix A. Equations A-29 to A-31 calculated the manpower used to produce steam. Equations A-32 to A-40 calculated the cost of spare parts and consumables. The total cost of steam was determined by Equation A-41. Datasheets 1, 4, 5, and 6 were used to provide data on consumables, manpower, steam production, and repairs.

Fossil fuel offsets were determined by Equation A-28 in Appendix A. The offsets were calculated by subtracting the quantity of fossil fuels (fuel oil, electricity, and front-end loader diesel fuel) consumed by the HRI from the quantity of fossil fuels saved by the HRI. The fossil fuels saved were equivalent to the steam energy from solid waste divided by boiler efficiency, and the result was converted to barrels of oil equivalent. The final result was the total barrels of oil equivalent saved by the HRI.

Thermal efficiency was determined by using Equations A-17 to A-23 in Appendix A. Information on energy-producing parameters was obtained from Datasheets 1 and 4. The thermal efficiency was calculated by dividing the steam energy by the supplied energy from solid waste and fuel oils.

Incineration time was measured by taking the total operating time for solid waste incineration plus waste oil only combustion and dividing by the total number of weeks the HRI was studied.

Maintenance man-hours were calculated as the total number of man-hours spent in preventive maintenance divided by the number of hours the HRI was operated. Corrective maintenance, MTTR, was determined by the length of time needed to repair the failures divided by the number of failures.

Subsystem Analysis

Each of the subsystems was analyzed for consistent failures, design problems, or good design features. The failures were determined from Datasheets 3 and 6 and were expressed as the number of failures for each piece of equipment. Design problems and good design features were determined from equipment analysis and interviews with plant personnel.

RESULTS

This section presents the results of the data analysis conducted at NS Mayport. The results are separated into three major subsections: mission analysis, operational parameter analysis, and subsystem analysis. The projected results were determined by applying curve-fitting techniques to the actual results calculated for each of the six 6-month sections in Table 2. Table 3 is a comparison of the projected results versus the predicted or design results.

Mission Analysis

The results of the mission analysis are presented in this section. Specific recommendations on improving mission performance will be given in the Subsystem Analysis Results section.

Mission 1. The Mission 1 RAM parameters are plotted on Figures 4 to 6. It can be seen from each of the figures that the RAM parameters on the average improved over the six analysis periods. This improvement occurred because design problems in the HRI were being corrected (drain piping replacement, relief stack modification); plant personnel were gaining experience on how to operate the HRI; and a more consistent routine maintenance program was being conducted.

The projected steady-state value for reliability was 58% based on least square curve fitting of Figure 4. This value was 25% lower than the predicted value of 77% (Ref 5). This reduction is due to operational problems with the crane, front-end loader, ram cylinders, and I.D. fan.

The projected value for availability was 82% based on trend analysis of Figure 5. This value is 9% lower than the predicted value. Better performance would be realized if a more reliable crane and solid rubber or foam-filled front-end loader tires were used.

The projected value for maintainability was 0.1 man-hr/ton of waste or 0.15 man-hour of maintenance/operating hour. This value was obtained from the Figure 6 analysis and is equal to the predicted value. Table 4 lists the number of failures and maintenance actions that occurred during the study period. Eighty failures and 31 other actions for a total of 111 maintenance actions occurred. The principal problem areas were the crane, ash conveyor, hydraulic feed ram cylinders, and the front-end loader.

Mission 2. The Mission 2 reliability is plotted in Figure 7. The availability for Mission 2 is the same as Mission 1 availability on Figure 5. The availabilities are the same because the HRI did not incinerate solid waste without producing steam (Mission 1 time categories equal Mission 2 time categories). Reliability is different because boiler failures and other actions were not included in the calculations. In general, each of the parameters improved over the six analysis periods for the same design and operation changes and maintenance procedures that affected Mission 1 performance.

Reliability was projected to be 61% based on least squares curve fitting on Figure 7. This value is 27% lower than the predicted value. Availability was projected as 82% (9% short of goal) from Figure 5. The recommendations for improving Mission 2 performance are the same as for Mission 1 because Mission 1 and 2 had the same operating characteristics.

Sixty-four failures and 22 other actions occurred over the six analysis periods (Table 4). This is 23 maintenance actions less than Mission 1 because boiler failures and other actions were removed from the calculations. The principal problem areas were the crane, front-end loader, and ram cylinders.

Mission 3. The Mission 3 reliability and availability are plotted on Figures 8 and 9, respectively. It can be seen from the figures that, on the average, the parameters improved. The improvement occurred because drain piping problems were corrected and improved operation and maintenance techniques were being utilized. Also, Mission 1 performance improved, which increased Mission 1 and 3 operating times.

The projected value for reliability was 95% based on trend analysis of Figure 9. This value is 8% higher than the expected value of 88%. The improvement occurred because few Mission 3 failures occurred in the last study periods.

Availability was projected to have a value of 91% from Figure 10 analysis. This value is only 1% higher than the expected value.

Twenty-three failures and eight other actions for a total of 31 maintenance actions occurred under Mission 3 criteria (Table 4). This is a reduction of 80 maintenance actions over Mission 1 performance. The reduction occurred because the receiving and ash subsystem problems were removed. The principal Mission 3 problems were feedwater equipment and the I.D. fan.

Operational Parameter Analysis

Waste Generation. NS Mayport generated an average of 125.7 tons of waste per week or 25.1 TPD during the study period. The HRI was able to utilize an average of 22.5 TPD of this waste. Solid waste generation data were available for 121 weeks of the 153-week study. During this time the activity generated 15,205 tons (incinerated plus hand-rejected waste data). The HRI utilized the 15,205 tons over a 135-week period (22.5 TPD).

The 25.1 TPD actual waste generation rate was 37% lower than the design value of 40 TPD. The shortfall was caused by the nature of the original planning studies. The studies were conducted for short periods of time (less than 2 weeks), which is statistically insignificant when compared to the long-term operation of the HRI. This was proven by examining the variation in solid waste generated over the study period. The quantity of waste varied from 1,750 to 4,466 tons per 6-month period or 14 to 34 TPD.

It is recommended that more realistic studies of waste generation rates be conducted before an HRI is designed. NCEL has developed a recommended survey method in which accurate data for planning purposes can be obtained (Ref 12). Proper sizing of HRI equipment to match the waste generated is necessary to prevent underutilization of expensive capital equipment.

Incineration Rate. Figure 10 is a plot of the solid waste incineration rate during the study period. The incineration rate increased for the first five analysis periods, but decreased in the sixth. The decrease was a result of the numerous ram cylinder failures that occurred in the sixth period. There were two reasons for the increase in incineration rate for the first five periods. The main reason was better equipment operation and waste sorting techniques. The second reason was a lack of demand for the steam during the beginning of the analysis due to the inadequate distribution network for the HRI. This situation was corrected in May 1983 when a valve was repaired that allowed access to other activity steam lines.

The projected long-term average for the incineration rate was 1.75 TPH. The projected incineration rate was essentially the same as the design rate of 1.67 TPH. The incineration rate was adjusted based on the waste generation rate and the incinerator operating time, so the HRI achieved its design goal for average incineration rate. On the average, the HRI incinerated 21.1 TPD (14,234 tons over 135 weeks).

Ash Production. The HRI produced 4,286 tons of wet and fly ash while incinerating 14,234 tons of solid waste. These numbers do not include the waste received from 4 Oct 1982 to 24 Jan 1983 because wet ash, fly ash and rejected waste data were not reported during this time. This means that the HRI produced 0.30 ton of ash per ton of waste incinerated or 0.5 TPH for the predicted incineration rate of 1.75 TPH. This equaled the expected value of 0.30 ton/ton.

Landfill Reduction and Cost Savings. The primary objective of the HRI was to reduce the quantity of waste entering the local landfill. This landfill reduction was 9,948 tons or 65% of the waste delivered to the HRI. This value was based on 5,257 tons disposed in the landfill, compared to 15,205 tons delivered to the HRI. The projected value was 7% lower than the expected value of 70%. The shortfall was due to the greater than expected use of waste sorting required to improve incinerator performance.

The projected cost savings were $26,600/yr based on 22.5 TPD received by the HRI and a $7/ton waste disposal cost. This value is 48% lower than expected due to the shortfall in actual waste generation and incineration time.

Steam Production. The HRI produced 101,297,833 pounds of steam, using 522,059 gallons of fuel and waste oil and 16,373 tons of solid waste. This was broken down into projected steam production values of 3,800 pounds of steam per ton of waste from Figure 11, and 72 pounds of steam per gallon of oil as calculated in Appendix B. Based on the predicted incineration rate of 1.75 TPH and a nominal oil firing rate of 10 gal/hr, the HRI produced 7,370 pounds of steam per hour or 8.7 MBtu/hr.

This projected value is 26% lower than the predicted value of 10,000 lb/hr. The shortfall was caused by the reduced thermal efficiency and incineration rate parameters.

Average Steam Cost. Figure 12 is a plot of steam cost (based on 1981 dollars) which in general decreased over the study period. The steam cost for the last 6-month period was higher than the previous value, but this was caused by the large number of failures in the feed ram cylinders. Assuming a 1981-83 energy inflation rate of 10% and a 1981 cost of $5.50/MBtu, the estimated long-term average for steam cost was $6.05/MBtu (1983 dollars) of steam produced. This value is 30%

below the 1983 cost of $8.70/MBtu for steam produced at NAS Jacksonville. This cost difference is primarily a function of fuel savings. The HRI and boiler costs did not include capital recovery, and the HRI cost did not include any savings from the reduction in solid waste disposal costs. The projected cost savings were $102,320/yr based on producing a potential of 38,610 MBtu of steam per year (Appendix B).

Fossil Fuel Offsets/Thermal. The fossil fuel offsets were projected to be 0.75 BOE/ton of waste incinerated. This value was based on trend analysis of Figure 13. The HRI saved a total of 10,590 BOE by using solid waste during the 3-year study period.

The expected performance was 240 BOE/wk, while the actual value was 79 BOE/wk. The difference was caused by three factors. First, the waste generation rate was only 63% of the predicted value. Second, the thermal efficiency was 13% lower than expected. Finally, incineration time was 32% lower than the expected value of 120 hours. These factors combined to severely reduce the fossil fuel offsets.

The estimated long-term average for HRI thermal efficiency was 48%, based on the total quantities of energy used and produced for the study period. The design goal for the HRI was 55% compared to a typical thermal efficiency of 78% for a stoker coal boiler. Thermal efficiency for incinerating solid waste only was 41% (Appendix B) and for fuel oil only was 63% (Ref 13).

The reduction in efficiency was due to the inefficient distribution of combustion air. European HRIs supply the combustion air from underneath the waste (Ref 14). This underfire method promotes better oxygen contact and helps mix the waste. Originally, the Mayport HRI was designed with underfire air in the hearth section. However, this caused a number of slagging problems in the hearth and the underfire air was stopped. The slagging occurred because the waste on the hearth was only moved by the feed ram once every 2 to 4 minutes. The thick layer of waste on top of the hearth concentrated the air at the waste-hearth interface. This created high temperature areas near the hearth drop-off which caused slagging. Underfire air should only be used in areas where the waste is mechanically moved (grates) so that adequate waste-air mixing can occur.

The Mayport HRI, which supplies air from above the waste (overfire), must supply more air to properly mix and combust the waste. Therefore, the Mayport HRI used 150% excess air (Ref 13) (air in addition to that needed for stoichiometric conditions) compared to 100% excess air for the European design (Ref 14).

The slight variations in thermal efficiency (Table 2) were caused by changes in the energy value of the solid waste. The value 5,134 Btu/lb used in this report was measured during a 3-day test at NS Mayport (Ref 13). This value was not accurate because of the highly variable nature of solid waste, and the inaccuracy had an effect on thermal efficiency.

This effect can be seen in Figure 14. The HRI produced a set quantity of steam energy and this quantity was independent of any inaccuracies in the assumed energy value of the solid waste. If the actual waste energy value had been 5,600 Btu/lb, the thermal efficiency would be 45% (6% lower than the original value). The extra energy input of 466 Btu/lb available from the solid waste would not have been used because the energy output remained constant. Conversely, an energy value of 4,500 Btu/lb would give a thermal efficiency of 52% (9% higher) because the lower energy from the waste would be used more effectively. It can be seen from Figure 14 that a 9% change in energy content changed the thermal efficiency by 11%. Therefore, the slight variance in thermal efficiency over the six study periods could be caused by changes in the energy value of the waste. However, the large decrease in actual performance versus expected performance could only be caused by equipment, design, or operational procedures and not by changes in energy value.

Incineration Time. Solid waste incineration time is plotted in Figure 15. It can be seen that incineration time increased over the first three periods and then leveled off for the last three periods. Actual solid waste incineration time averaged 81.4 hr/wk (5,942.09 hours for 73 weeks) for the last three periods, with an additional 7.4 hr/wk (540.67 hours for 73 weeks) from burning waste oil when no solid waste was available. The total average operation time for the HRI was 88.8 hr/wk.

The projected incineration time of 88.8 hr/wk is 26% lower than the design value of 120 hr/wk. This reduction was caused by problems with the crane, feed ram, cylinders, and I.D. fan.

Maintenance Man-Hours. Routine maintenance on weekends was scheduled as 7.5 hours for a 2-man crew. This means that 15 man-hr/wk of scheduled routine maintenance were performed on the HRI, which equaled the expected value. Corrective maintenance was increasing in the last three periods and required 11.5 hours during the last 6-month period. Future values could be expected to meet or exceed these values as the HRI equipment ages.

Subsystem Analysis

Receiving Subsystem. The receiving subsystem had the worst performance of the four subsystems. Forty-three of 80 failures and 10 of 31 maintenance actions occurred in this subsystem (Table 4). The principal problem areas were the feed rams, crane, and the front-end loader.

The feed ram cylinder failures occurred in 19 out of 80 failures with 2, 3, 1, 3, 4, and 6 failures over the six respective study periods. The ram warped during the first two periods because the ram was overextending into the primary chamber. This exposed the cylinder to excessive heat, caused thermal warpage, and increased the pressure on the ram cylinder and seals, thus causing failures. The problem was corrected by adding an extension to the rear of the ram which reduced the required cylinder stroke and the pressure on the cylinder seals. Also, the ram guide wheels which had been flattened on one side from extended use and inadequate maintenance were replaced. A bi-annual inspection of the ram is necessary so that any repairs or realignments can be made. A weekly inspection and regreasing of the ram guide wheels is necessary to maintain effective performance. Also, a set of rod seals, packing, and hydraulic fluid should be stored to permit faster repairs.

The crane failures were an inherent part of the Mayport HRI operation -- 17 out of 80 failures, with 4, 2, 3, 3, 4, and 1 failures during the six periods. The crane was an original design, and persistent failures of the brake shoes, cables, controls, electrical supply system, and drive gears indicate an inadequate design of these parts. To reduce the number of crane failures, the crane selected should be a standard, off-the-shelf item of proven design. Also, a program of preventive maintenance with monthly inspections and an adequate inventory of spare parts (brake shoes and parts) would reduce lost time from any crane failure.

The front-end loader caused the last seven failures in the receiving subsystem. These failures were partly from flat tires, which could be prevented if solid rubber or foam-filled tires were used.

The best feature of the receiving subsystem was the design of the tipping floor and the storage pit. The floor and pit were considered by the plant operators to be adequately sized for the quantity of waste delivered to the HRI (25 TPD). The tipping floor had an area of 6,000 ft^2, the pit a volume of 8,856 ft^3. This translated into a design value of 230 ft^2/TPD for the tipping floor and 340 ft^3/TPD for the storage pit.

Incineration Subsystem. The incineration subsystem had the second best performance with 13 failures and four other actions. Six failures and three other actions were stoker or tuyere failures which would not affect Mission 3 performance (Table 4).

The principal equipment problem area for the incinerator was the stoker grates with four failures and three other actions. This problem was corrected in the last two analysis periods (no failures occurred) by slowing down the grates to allow for better waste burnout, and by conducting a more careful waste presorting program. It is recommended that the presorting program be included as part of the HRI operational procedures to reduce the number of stoker failures.

The other incinerator equipment failures occurred only once or as different failures in one piece of equipment. No recommendations are made or are necessary regarding these situations.

The other incineration subsystem problems were excessive flyash carryover and slagging, which increased maintenance time and refractory wear. A large part of the preventive maintenance performed during the weekend shutdown was required to remove the excessive quantities of flyash, which settled in both incinerator chambers, the boiler, and both stacks, and the excessive slag from both incinerator chambers. The ash and slag were clogging passages between these subsystem components, restricting air flow, air detention times, and heat transfer rates. It is recommended that better combustion air distribution (underfire versus overfire) be used to reduce the quantity of combustion air required, thus reducing air flow rates and particle carryover.

The excessive refractory wear was caused by the removal of ash and slag from the walls of the incinerator chambers. The refractory had worn through to the insulation block at the hearth drop-off and was severely damaged in a number of other locations. The majority of refractory is therefore scheduled for replacement in June 1984. It is recommended that slag removal be carefully done to reduce refractory damage, and that wear-resistant, high-alumina-content refractory be used wherever the waste bed comes in contact with the walls.

Boiler Subsystem. The boiler subsystem had the second worst performance with 16 failures and seven other actions (Table 4). The major problem areas were the feedwater equipment and the I.D. fan. Also, design changes were made in the drain piping and the steam system.

The feedwater equipment caused seven failures. These failures were mainly pump, piping, and value problems. The pump drive shafts were not correctly aligned, creating undue stress on the pump seals. It is recommended that a bi-annual overhaul and inspection to replace worn parts, and to realign and clean the system be conducted to reduce the number of failures and improve performance.

The I.D. fan motor burnout due to dust accumulation was the worst problem, with repair times ranging from 28 to 40 hours. Bi-annual overhaul and inspections to replace worn parts and to realign and clean the system should reduce the time lost from these types of failures.

Two design corrections to the boiler subsystem were made during the 3-year test period. The first was the replacement of the drain piping from the boiler blowdown tank and the ash quenchtank. This was done because the hot water warped the plastic piping, which then broke. A metal or concrete pipe would not be affected by the hot water. The drain piping from the quenchtank also experienced another type of problem. The hardness and high pH of the quench water caused scaling and clogging of the pipe. Water treatment to reduce pH and control scaling or monthly mechanical routing out of the drain pipe could be necessary. The second correction was the addition of a steam separator to the top of the boiler to correct the high water content of the steam.

Ash Subsystem. The ash subsystem had the best subsystem performance with eight failures and ten other actions (Table 4). All of these problems occurred in the ash conveyor.

The ash conveyor caused eight failures, but all of these failures occurred in the first three periods. These failures were corrected by more careful waste presorting and by slowing down the stoker, which allowed for a better waste burnout. These steps reduced the number of large, bulky, and nonburnable items being jammed between the ash chain and gears that caused shear pin failure. Future conveyor design should ensure no moving parts enter the water. This should reduce the potential for jams and reduce the amount of lubrication required for the moving parts.

CONCLUSIONS

The HRI at NS Mayport did not meet its expected performance goals in most of the categories studied. This shortfall was caused by poor performance and overdesign of HRI equipment. A number of these problems were corrected over the study period, and as a result, the performance reached acceptable levels.

RECOMMENDATIONS

NCEL recommendations are organized into areas of planning, design, operation, and maintenance. These recommendations are primarily for the design elements reviewed in this report that should be carefully considered in an HRI being designed for any Navy facility.

Planning Criteria

- Prior to HRI design, conduct a long-term study to determine the variability of waste quantities and composition. This study should be conducted as outlined in the new survey method developed by NCEL (Ref 12). This method collects data for 25 to 30 days over a year's period, and then analyzes the data statistically to provide accurate results. The benefit of this procedure is that the HRI can be properly designed for the type, quantity, and variation of waste available. This will reduce operation and maintenance costs and improve reliability.

Design Criteria

- Design the feed system such that the ram hydraulic cylinder rod does not become heated by or extend into the primary chamber to reduce seal failure from an overheated rod.

- Select drain piping and sizes for high temperature flows to prevent pipe buckling and blockage. Water treatment or mechanical routing may be necessary to reduce scale buildup.

- Select a standard off-the-shelf crane with proven performance.

- Design combustion air distribution as primarily underfire air to reduce the quantity of air required and the resultant flyash carryover.

- Design ash conveyor so that no moving parts enter the water of the quenchtank.

- Construct at least a 230 ft^2/TPD and a 340 ft^3/TPD tipping floor and storage pit, respectively.

- Design the boiler such that the necessary steam characteristics are obtained. This includes the use of extra equipment, such as a steam separator, if necessary.

- Use high quality alumina refractory, with additional wear protection for the refractory in contact with the moving refuse bed.

Operating Criteria

- Remove large, bulky, and dangerous items from the waste by handsorting on the tipping floor.

Maintenance Procedures

- Perform a weekly slag removal and cleaning of each boiler tube.

- Perform a monthly inspection of the crane to check for worn brake shoes or drive gears.

- Perform a bi-annual inspection and overhaul of the feed ram to correct warpage or misalignment. Perform weekly greasings and inspections of the feed ram guide wheels.

- Perform a bi-annual inspection and overhaul of the I.D. fan to check for misalignment of the fan and dust in the motor.

- Perform a bi-annual inspection and overhaul of the feedwater equipment and piping to check performance; clean and realign valves and pumps.

- Have a set of crane brake parts and a set of ram seals, packing, and hydraulic fluid, plus any contractor recommendations for other parts, as a spare parts store.

- During slag removal from refractory, take precautions to reduce damage to the refractory (leave some slag).

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NOMENCLATURE

ACS	Average cost of steam (see Equation A-41), \$/MBtu
A_o	Operational availability as a probability (see Equations A-10 through A-12), expressed as a decimal
CC	Total cost of consumable supplies not included in CF, \$
CF	Total cost of fuel used (virgin and waste oil, diesel, and electrical power), \$
CF_{FFO}	Conversion factor, Btu to BOE, 5.8×10^6
CMR	Corrective maintenance ratio (see Equation A-15), man-hr/operating hr
CP	Total cost of parts used in repair, maintenance, and replacement, \$
DR	Efficiency of solid waste weight reduction through incineration (see Equation A-44), %
d_w	Density of make-up water, 8.3 lb/gal
E_{wo}	Steam energy from waste oil, Btu
E_{fo}	Steam energy from fuel oil, Btu
E_{sw}	Steam energy from solid waste, Btu
E_T	Electrical cost (see Equation A-37), \$
E_t	Electrical energy supplied to the HRI (see Equation A-25), Btu
e	Base of Naperian log system, 2.718
e_t	Electricity conversion factor, 11,600 Btu/kW-hr
FFO	Fossil fuel offsets (see Equation A-28), BOE
FF_B	Fossil fuel energy used by the boiler, Btu
FF_H	Fossil fuel energy consumed by the HRI, Btu
FR_o	Nominal oil firing rate, gal/hr
FR_{om}	Maximum oil firing rate, gal/hr

HRI Heat Recovery Incinerator

H_{df} Energy from diesel fuel supplied to front-end loader (see Equation A-26), Btu

H_{fo} Energy derived from fuel oil supplied to HRI (see Equation A-20), Btu

H_{hri} Energy supplied to HRI (see Equations A-18 through A-23), Btu

H_{sw} Energy derived from solid waste and supplied to the HRI (see Equation A-19), Btu

H_{w} Energy derived from make-up of water supplied to the HRI (see Equation A-22), Btu

H_{wo} Energy derived from waste oil and supplied to the HRI (see Equation A-21), Btu

h_{df} Estimated higher heating value from diesel fuel (Ref 10), 58,725 Btu/ton of solid waste

h_{fo} Higher heating value of fuel oil, 138,810 Btu/gal

h_{s} Average steam enthalpy produced by the HRI, 1,185 Btu/lb

h_{sw} Higher heating value of solid waste (Ref 13), 5,134 Btu/lb

h_{w} Enthalpy of water at 80°F, 48 Btu/lb

h_{wo} Higher heating value of waste oil, 134,957 Btu/gal

I.D. Induced draft fan

IR Incineration rate of the HRI facility (see Equation A-42), ton/hr

M_{a} Quantity of fly ash and slag, tons

M_{3} Quantity of solid waste that is hand-rejected, tons

M_{12} Solid waste fired in the HRI, tons

M_{14} Wet ash removed, tons

M_{15} Steam produced, pounds

M_{17} Makeup water supplied to HRI, gallons

M_{19} Blowdown, gallon

M_{20}	Fuel oil supplied to HRI, gallon
M_{21}	Waste oil supplied to HRI, gallon
M_{22}	Diesel fuel oil supplied to front-end loader, gallon
MI	Maintainability Index (see Equation A-16), maintenance man-hr/operating hr
Mt_a	Operating labor spent on the HRI during t_a, man-hr
Mt_b	Maintenance labor spent on the HRI during t_b, man-hr
Mt_c	Maintenance labor spent on the HRI during t_c, man-hr
MTBF	Mean Time Between Failures (see Equations A-1 through A-3), hour
MTTR	Mean Time to Repair (see Equation A-13), hour
MTBMA	Mean Time Between Maintenance Action (see Equations A-4 through A-6), hour
NAS	Naval Air Station
NCEL	Naval Civil Engineering Laboratory
N_f	Number of failures that caused shutdown of the HRI or subsystem
N_{ma}	Number of maintenance actions
N_r	Number of repairs
NS	Naval Station
PC	Average cost of steam produced at the activity, $/MBtu
PLR	Landfill reduction by weight for solid waste accepted at HRI (see Equation A-45), %
PMR	Preventive maintenance ratio (see Equation A-14), man-hr/operating hr
R	Reliability as a probability (see Equations A-7 through A-9), expressed in decimal numbers
RAM	Reliability, availability, and maintainability
RCRA	Resource Conservation Recovery Act
R_o	Rate of steam production from oil, lb/gal

R_{sw}	Rate of steam production from waste, lb/ton
S_o	Steam produced from waste oil and fuel oil, pounds
S_{sw}	Steam produced from solid waste, pounds
SCC	Specific consumable costs (see Equation A-33), $/MBtu
S_{HRI}	Steam energy produced by the HRI, MBtu
SOM	Specific operating man-hours (see Equation A-29), man-hr/MBtu
SP	Efficiencies of steam production (see Equation A-43), lb steam/lb solid waste
SRC	Specific repair and maintenance cost (see Equation A-32), $/MBtu
SRM	Specific repairs and maintenance man-hours (see Equation A-30), man-hr/MBtu
STM	Specific total man-hours (see Equation A-31), man-hr/MBtu
T	Total monitoring period (see Equation A-46), hour
T_{kwh}	Average kilowatts/hr supplied to the HRI from short-term test at NS Mayport (Ref 13), 169.31 kW/hr
TE	Overall thermal efficiency (see Equation A-17), %
TPD	Tons per day
t_a	Operating time for the specific HRI, subsystem, or mission, hour
t_b	Time spent in routine maintenance, hour
t_c	Time spent in repairs/replacements for the specific mission, hour
t_d	HRI idle time (operational), hour
t_e	HRI idle time (not operational) for the specific mission, hour
t_i	Incineration equipment operating period, hour
t_m	Mission time for reliability calculations, 120 hours
T_o	Average incineration time for oil only, hr/wk

T_{sw} Average incineration time for solid waste, hr/wk

W Wages, \$/hr

λ Failure rate for specific mission, 1/MTBF

TE_B Boiler thermal efficiency, 0.80

TE_{wo} Efficiency of fuel oil incineration (Ref 13), 0.63

TE_{sw} Efficiency of solid waste incineration

Table 1. Raw Data for the Six Study Periods

Item	Oct 80 to Mar 81	Apr 81 to Sep 81	Oct 81 to Mar 82	Apr 82 to Sep 82	Oct 82 to Mar 83	Apr 83 to Aug 83	Total
	Raw Data for the Following Periods--						
Incinerator Operation Time (t_a), *hr*	1,794.63	1,483.93	2,158.42	2,126.34	1,938.34	1,877.41	11,379.07
Operation Time, man-hr	6,390	5,026.6	7,044	8,300	8,176	7,360	42,296.6
Corrective Maintenance (t_c), hr	417.17	187.83	132.50	125.75	135	92.33	1,090.58
Corrective Maintenance, man-hr	957	278.5	173	139.5	70	-	1,618
Preventive Maintenance (t_b), hr	188	576.33	246	186.50	172.50	154.50	1,523.83
Preventive Maintenance, man-hr	679.5	1,907	746	347	332	296.5	4,308
Idle, but Operational (t_d), hr	1,008.60	869.92	1,101.41	1,315.25	1,699	1,269.42	7,263.60
Idle, but Not Operational (t_e), hr	944.01	1,306	714.93	572.15	431.92	47.33	4,016.34
Waste Oil Operation Time,[a] hr							
t_a Factor	215.26	-	124.59	527.40	602.09	283.74	1,753.08
t_c Factor	54.17	-	20.00	102.42	120.50	92.33	389.42
t_d Factor	-	-	42.25	126.25	275.84	138.58	582.92
t_e Factor	161.09	-	62.34	298.73	215.25	43.33	780.74
Waste Oil, gal	120,947	67,904	68,002	104,017	115,990	43,379	520,239
Fuel oil, gal	729	245	338	16	486	6	1,820
Make-up water, gal	2,285,100	1,541,900	2,749,350	3,685,100	3,263,600	2,252,300	15,775,550
Blowdown, gal	432,090	386,492	407,760	281,054	-	-	1,507,396
Solid Waste Incinerated, tons	1,904.92	1,671.36	3,231.36	3,287.10	3,307.84 (1,168.68)[b]	2,970.14	16,372.72 (14,233.56)[b]
Waste Rejected, tons	96.38	77.63	200.14	179.12	68.21[c]	349.39	970.87[c]
Wet Ash, tons	510.26	436.60	1,058	902.41	322.85[c]	1,001.20	4,231.32[c]
Fly Ash, tons	7.10	6.80	13.19	12.36	5.35[c]	10.11	54.91[c]
Steam, lb	15,342,923	9,567,119	19,769,560	18,865,086	22,323,600	15,429,545	101,297,833
Salt, lb	14,880	9,680	12,770	19,360	16,960	12,760	86,410
PO_4, lb	234	236	322	537	316.5	165.25	1,810.75
SO_3, lb	285.5	250	327.5	586.5	295	229	1,973.5
Repair Cost, $	17,197.00	5,815.40	4,995.75	4,346.02	841.47	-	33,195.64
Consumables Cost, $	451.32	472.44	620.35	390.00	-	-	1,934.11

[a]Each of these values was appropriately added to or subtracted from values to determine Mission 3 parameters (see Appendix A for mission definitions): t_a was added, t_c, t_d, and t_e were subtracted. This reflected the use of waste oil to produce steam when no solid waste was incinerated.

[b]Quantity of waste incinerated when the 16-week period from 4 Oct 82 to 24 Jan 83 was removed. This value was used to determine the normalized results for waste rejected, wet ash, and fly ash (see footnote c).

[c]For a 16-week period from 4 Oct 82 to 24 Jan 83, no values were reported for these categories.

Table 2. Results of Raw Data Analysis for the Six Study Periods

Item	Results of Analysis for Following Periods--					
	Oct 80 to Mar 81	Apr 81 to Sep 81	Oct 81 to Mar 82	Apr 82 to Sep 82	Oct 82 to Mar 83	Apr 83 to Aug 83
Mean Time Between Failures (MTBF)						
Mission 1[a]	85.5	114.1	196.2	151.9	149.1	234.7
Mission 2	112.2	164.9	239.8	177.2	193.8	234.7
Mission 3	251.2	296.8	761	633.4	846.8	2,161
Mean Time Between Maintenance Actions (MTBMA)						
Mission 1	56.1	92.7	102.8	125.1	114	234.7
Mission 2	66.5	123.7	154.2	141.8	138.5	234.7
Mission 3	201	247.3	285.4	663.4	846.8	2,161
Reliability (R)						
Mission 1	0.246	0.349	0.542	0.454	0.447	0.600
Mission 2	0.343	0.483	0.606	0.508	0.506	0.600
Mission 3	0.620	0.667	0.854	0.835	0.910	0.946
Availability (A_o)						
Mission 1	0.537	0.417	0.664	0.706	0.724	0.865
Mission 2	0.537	0.417	0.664	0.706	0.724	0.865
Mission 3	0.601	0.417	0.693	0.846	0.860	0.936
Mean Time to Repair (MTTR)[b], hr/repair	19.87	14.45	12.05	8.98	10.38	11.54
Maintenance, man-h.						
Preventive	0.379	1.285	0.346	0.163	0.171	0.158
Corrective	0.533	0.188	0.080	0.066	0.036	-
Total	0.912	1.473	0.426	0.229	0.207	0.158
Failure						
Mission 1	21	13	11	14	13	8
Mission 2	16	9	9	12	10	8
Mission 3	8	5	3	4	3	0
Maintenance Action (MA)						
Mission 1	32	16	21	17	17	8
Mission 2	27	12	14	15	14	8
Mission 3	10	6	8	4	3	0
Specific Total Man-hour Time (STM), man-hr/MBtu	0.460	0.663	0.354	0.410	0.338	0.436
Specific Operating Man-hour Time, (SOM), man-hr/MBtu	0.366	0.462	0.313	0.387	0.322	0.420
Specific Repair Man-hr Time, (SRM), man-hr/MBtu	0.094	0.201	0.041	0.023	0.016	0.017
Specific Repair Costs (SRC), $/MBtu	0.99	0.53	0.22	0.20	0.03	0.00
Specific Consumable Costs (SCC), $/MBtu	3.39	3.41	2.05	2.81	2.47	2.06
Steam Cost, $/MBtu	8.98	10.57	5.81	7.11	5.88	6.52
Fuel, oil/ton of waste	63.9	40.8	21.1	31.6	35.2	14.6
Steam Produced (SP), lb steam/lb waste	1.53	1.25	2.16	1.55	1.95	1.95
Steam Produced (SP), lb steam/gal oil	74.3	74.5	74.4	74.8	74.4	74.7
Incinerator Reduction Efficiency (DR), %	73.2	73.9	67.3	72.5	72.4	66.3
Percent Landfill Reduction (PLR), %	69.3	70.2	63	68.4	68	59
Processing rate, ton/hr	1.06	1.13	1.50	1.55	1.71	1.58
Thermal Efficiency, %	48.6	41.3	53.0	44.9	51.1	48.2
Fossil Fuel Offsets (FFO), BOE/ton	0.435	0.338	0.867	0.525	0.739	0.750

[a]See Appendix A for mission descriptions. [b]Corrective maintenance.

Table 3. Comparison of Expected and Projected Results

Parameter	Expected	Projected	Difference[a] (%)
Mission 1			
R, %	77	58	-25
A, %	90	82	-9
M, man-hr/ton	0.1	0.1	0
Mission 2			
R, %	84	61	-27
A, %	90	82	-9
Mission 3			
R, %	88	95	+8
A, %	90	91	+1
Waste generation rate, TPD	40	25.1	-37
Incineration rate, TPH	1.67	1.75	5
Ash production, ton/ton	0.3	0.3	0
Landfill reduction, %	70	65	-7
Cost savings, $/yr	51,000	26,600	-48
Steam production, lb/hr	10,000	7,370	-26
Fossil fuel offsets, BOE/wk	240	79	-67
Thermal efficiency, %	55	48	-13
Annual steam cost, $/MBtu	8.70	6.05	-30
Incineration time, hr	120	81.4	-32
Preventive Maintenance man-hr	15	15	0

[a](1 - projected/expected) x 100

Table 4. Failures and Other Actions by Mission and Subsystem[a]

Date	Mission 1			Mission 2			Mission 3		
	F	OA	MA[b]	F	OA	MA[b]	F	OA	MA[b]
Oct 80 - Mar 81	21	11	32	16	11	27	8	2	10
Apr 81 - Sep 81	13	3	16	9	3	12	5	1	6
Oct 81 - Mar 82	11	10	21	9	5	14	3	5	8
Apr 82 - Sep 82	14	3	17	12	3	15	4	-	4
Oct 82 - Mar 83	13	4	17	10	4	14	3	-	3
Apr 83 - Aug 83	8	-	8	8	-	8	-	-	-
Total	80	31	111	64	22	88	23	8	31

Subsystem

Date	Receiving			Incineration			Boiler			Ash			MA
	F	OA	MA[b]	F[c]	OA[c]	MA[b]	F	OA	MA[b]	F	OA	MA[b]	Total
Oct 80 - Mar 81	7	5	12	4(1)	-	4(1)	5	2	7	5	4	9	32
Apr 81 - Sep 81	5	-	5	2(1)	1	3(1)	4	-	4	2	2	4	16
Oct 81 - Mar 82	4	2	6	4(3)	2(2)	6(5)	2	5	7	1	1	2	21
Apr 82 - Sep 82	9	-	9	3(1)	1(1)	5(2)	2	-	2	-	2	2	17
Oct 82 - Mar 83	10	3	13	-	-	-	3	-	3	-	1	1	17
Apr 83 - Aug 83	8	-	8	-	-	-	-	-	-	-	-	-	8
Total	43	10	53	13(6)	4(3)	17(9)	16	7	23	8	10	18	111

[a]F = Failure, OA = Other Action, MA = Maintenance Action

[b]MA = F + OA

[c]Numbers in parenthesis were stoker and tuyere failures or other actions.

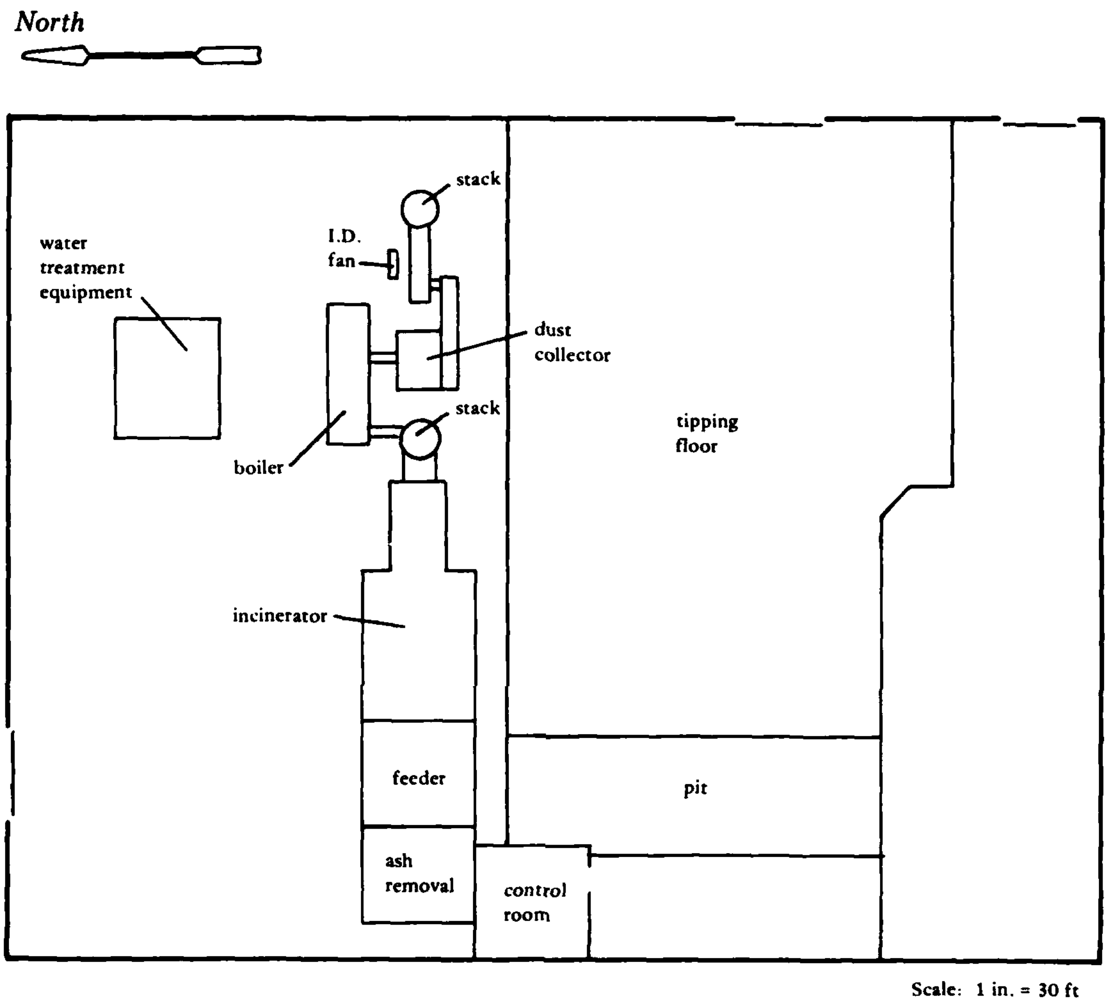


Figure 1. Layout of heat recovery incineration facility at Mayport Naval Station (Ref 13).

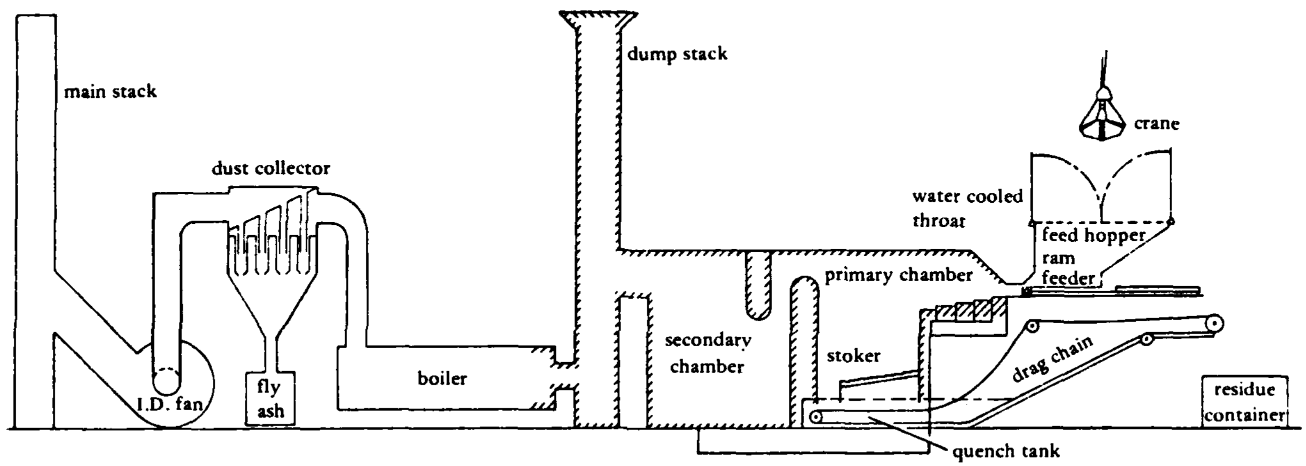
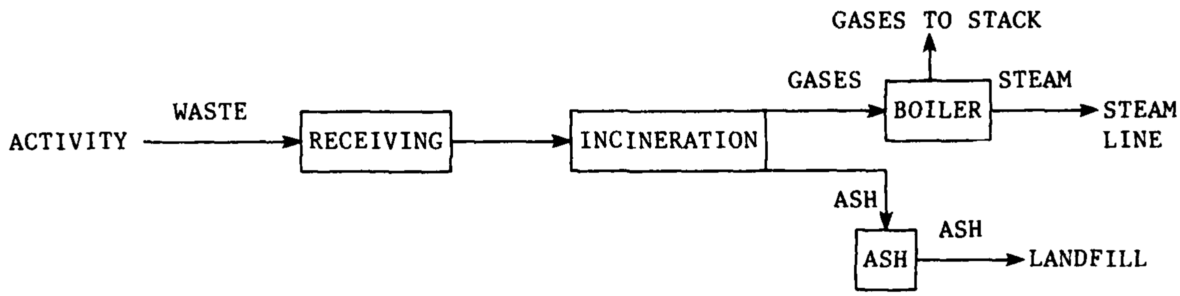
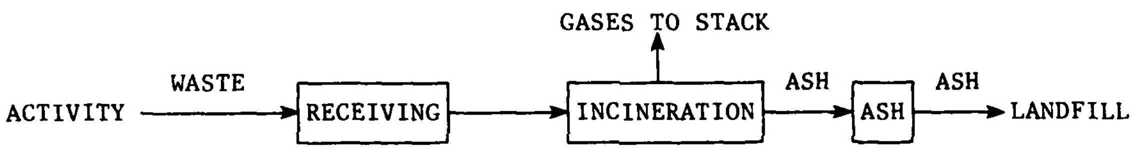


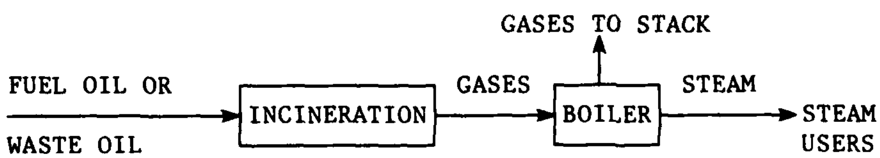
Figure 2. Relative elevations of the heat recovery incineration system at NS Mayport (Ref 13).



(a) Mission 1: Incinerate solid waste and produce steam.



(b) Mission 2: Incinerate solid waste only.



(c) Mission 3: Produce steam only.

Figure 3. Graphical depiction of HRI missions.

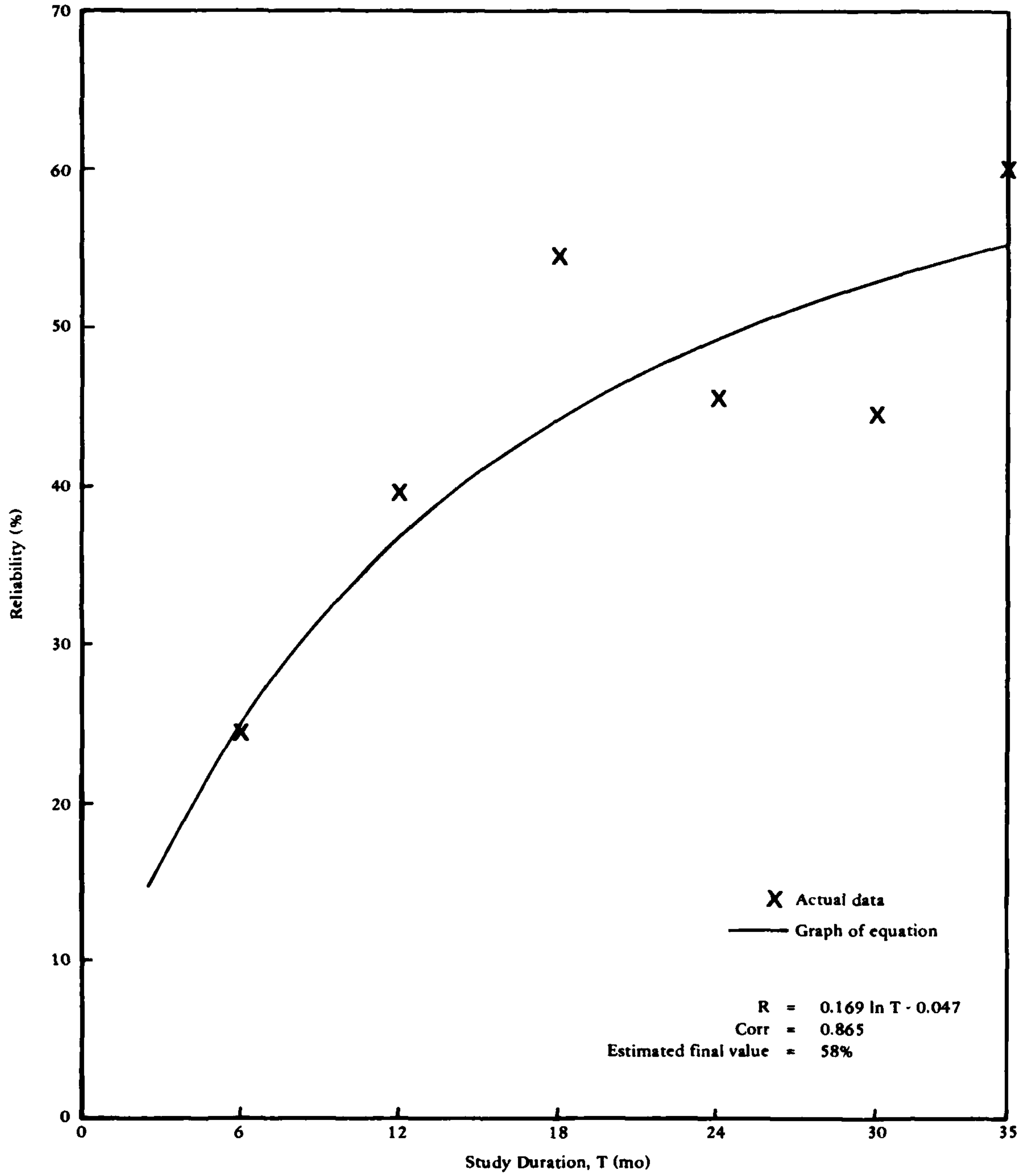


Figure 4. Mission 1 reliability growth over the study period.

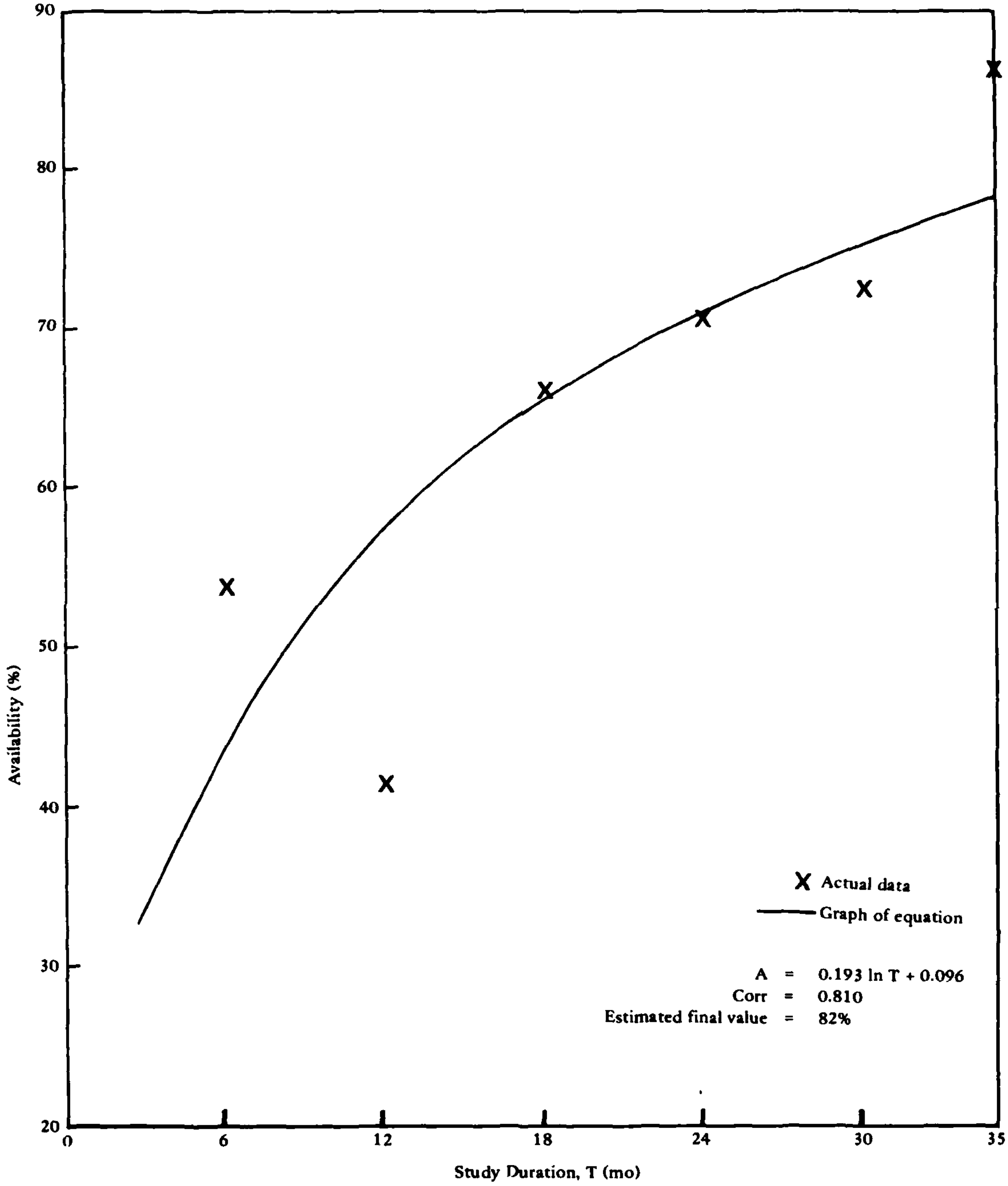


Figure 5. Mission 1 availability growth over the study period.

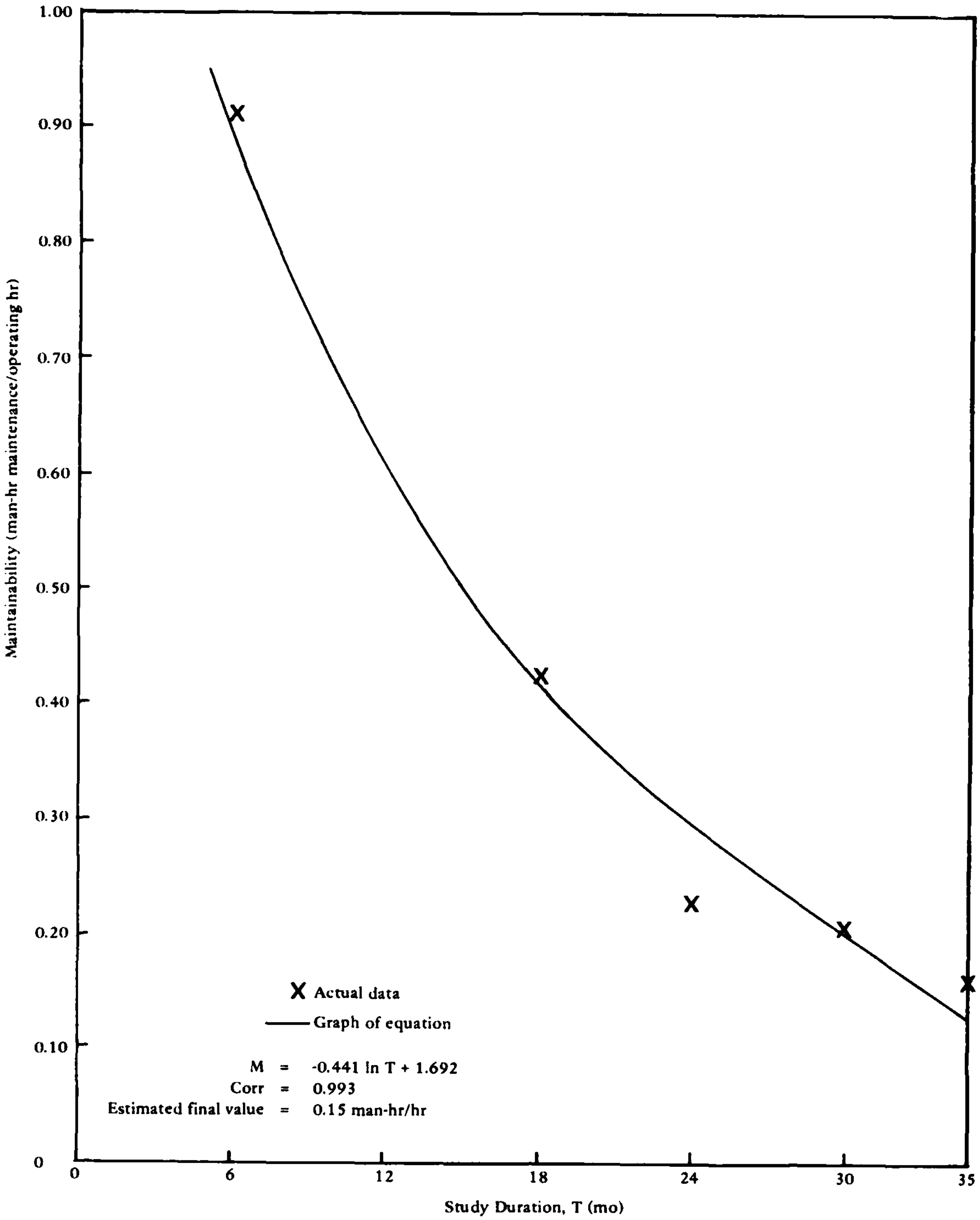


Figure 6. Mission 1 maintainability improvement over the study period.

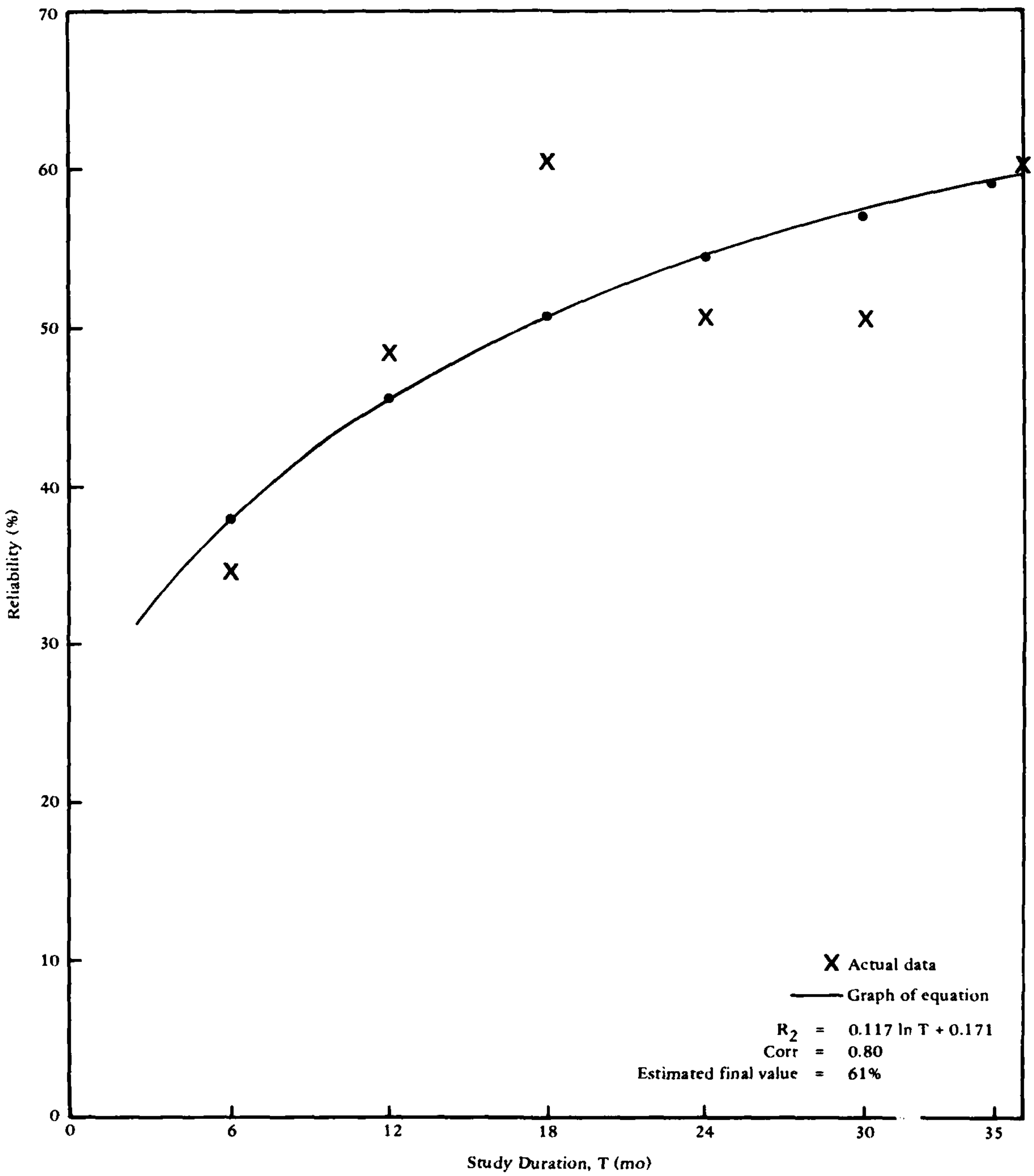


Figure 7. Mission 2 reliability growth over the study period.

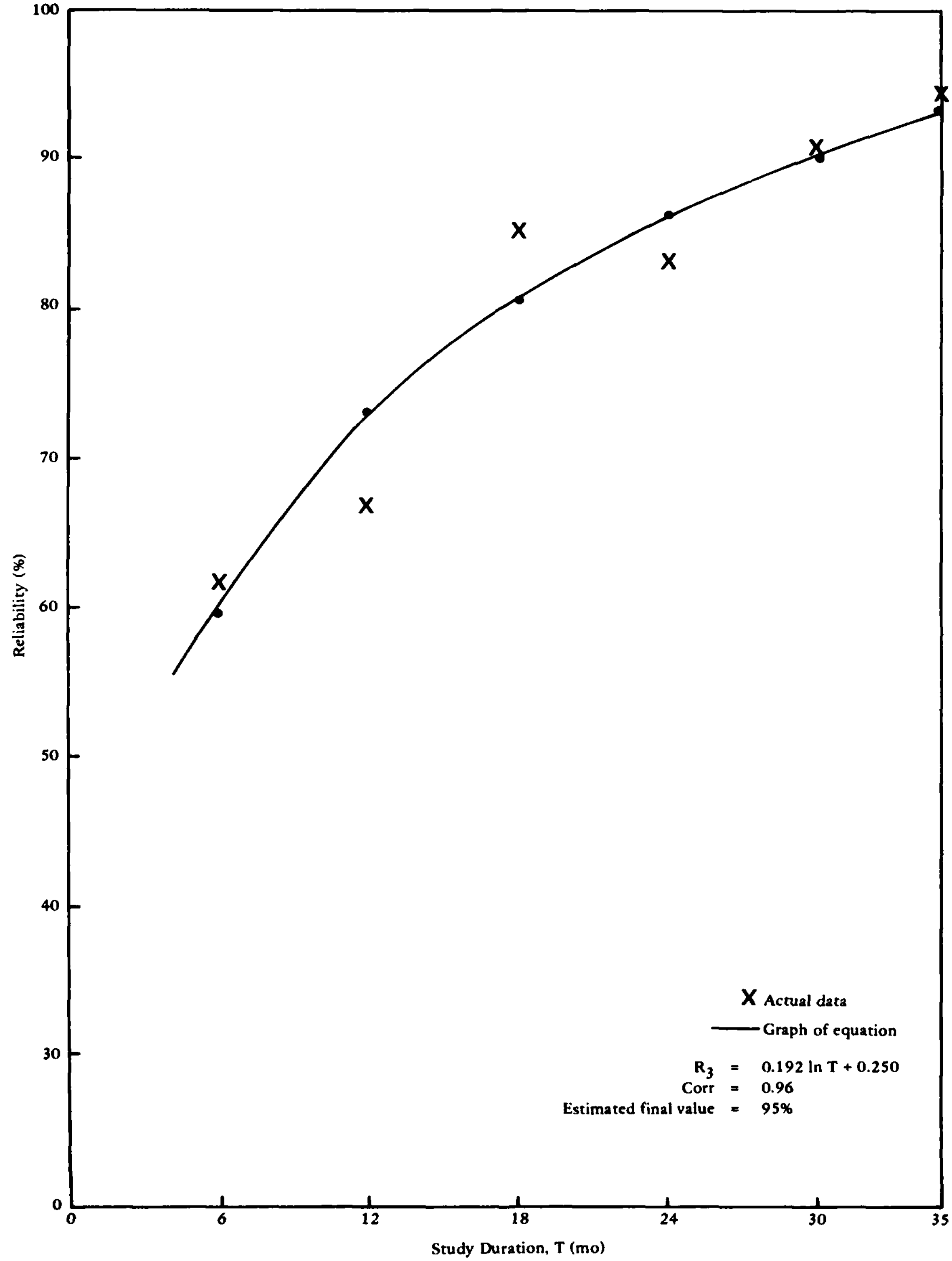


Figure 8. Mission 3 reliability growth over the study period.

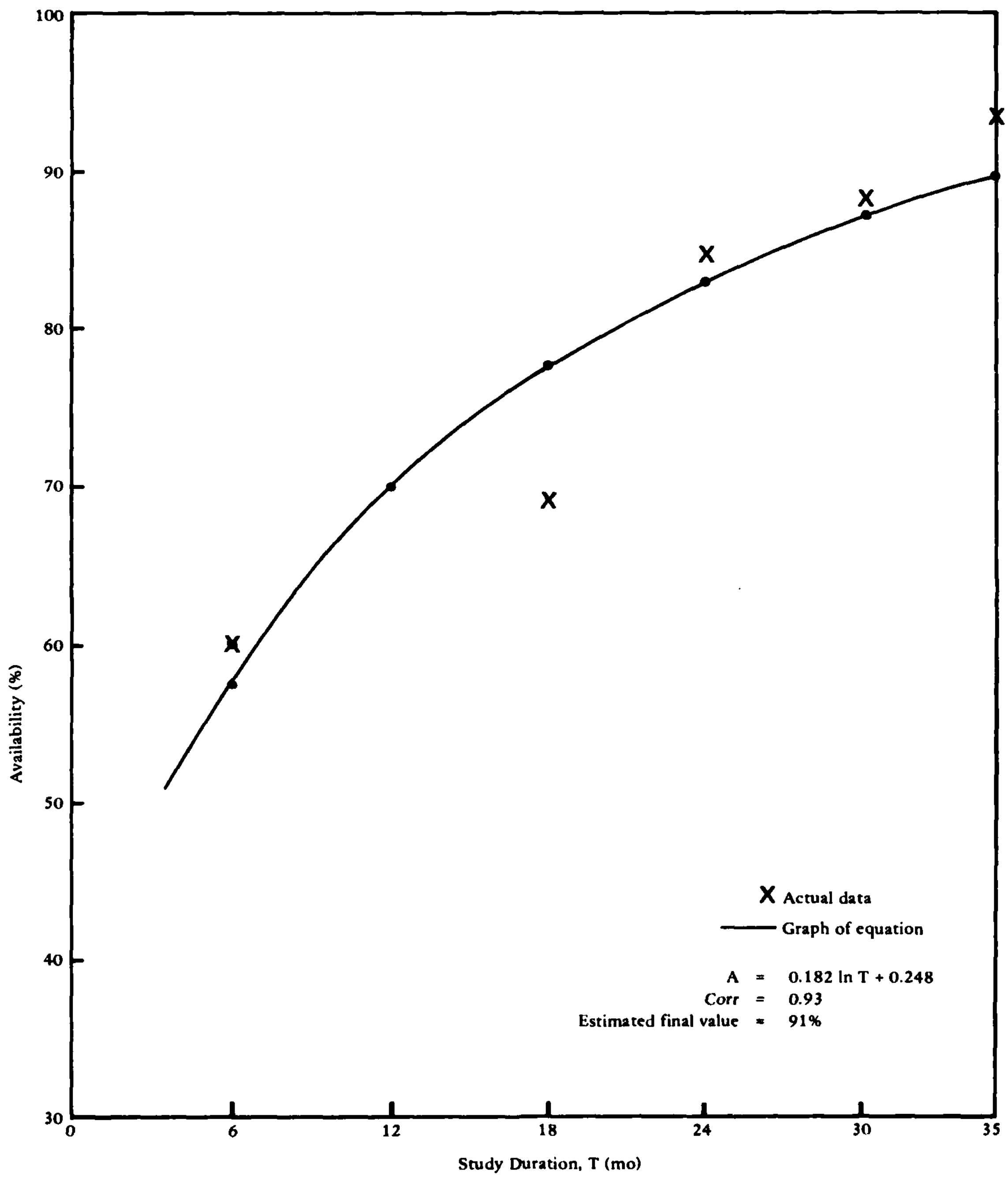


Figure 9. Mission 3 availability growth over the study period.

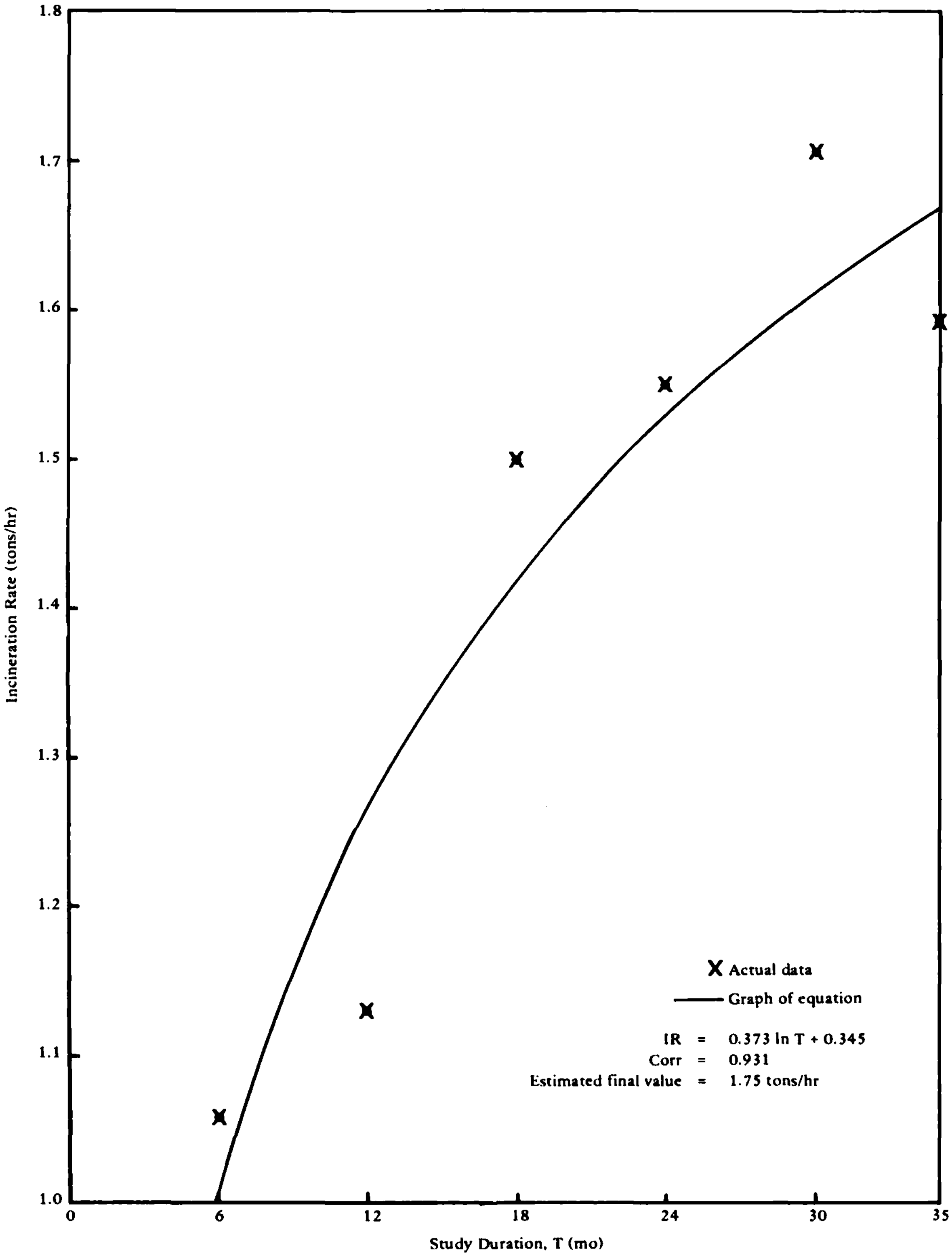


Figure 10. Incineration rate over the study period.

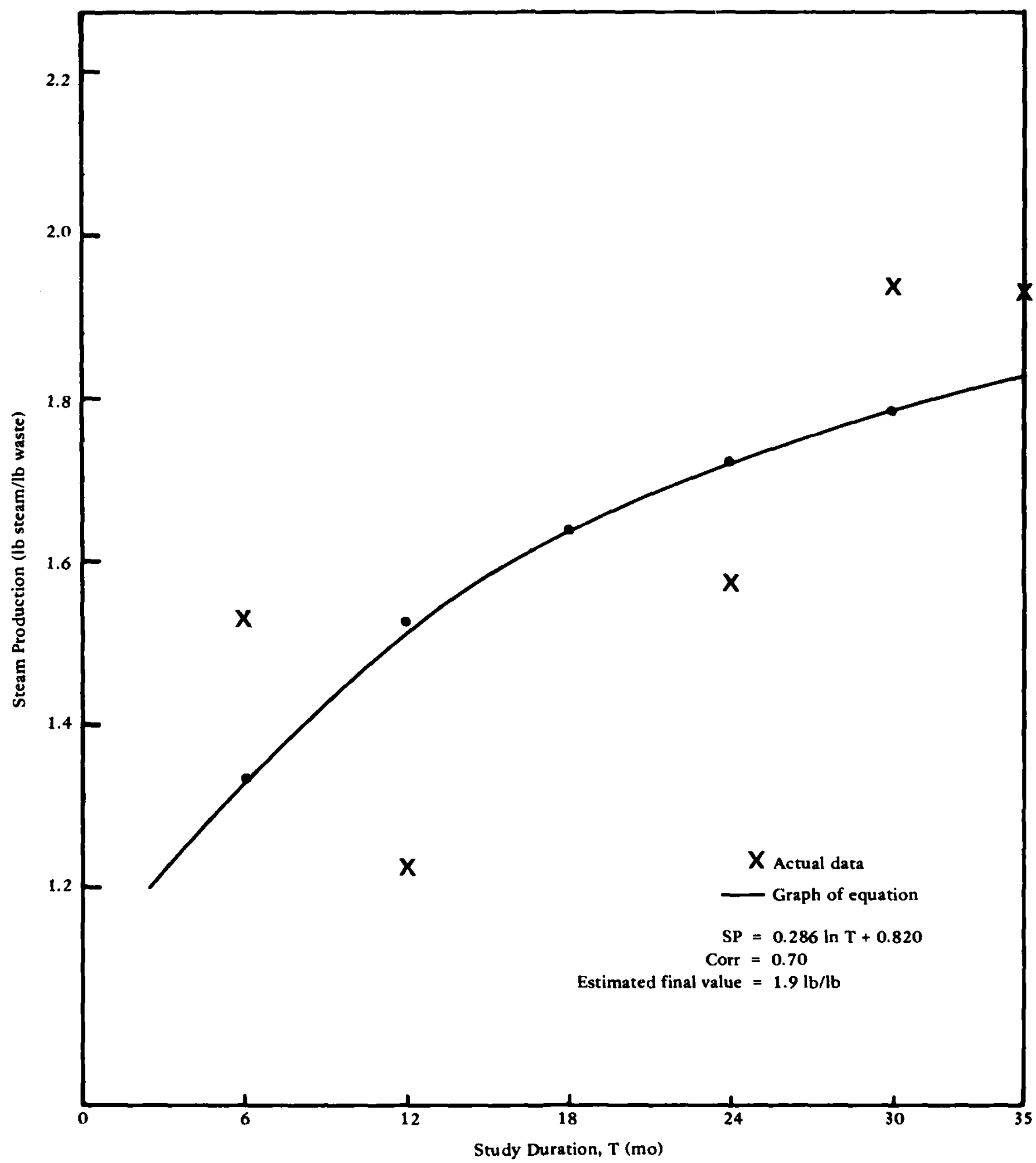


Figure 11. Steam production over the study period.

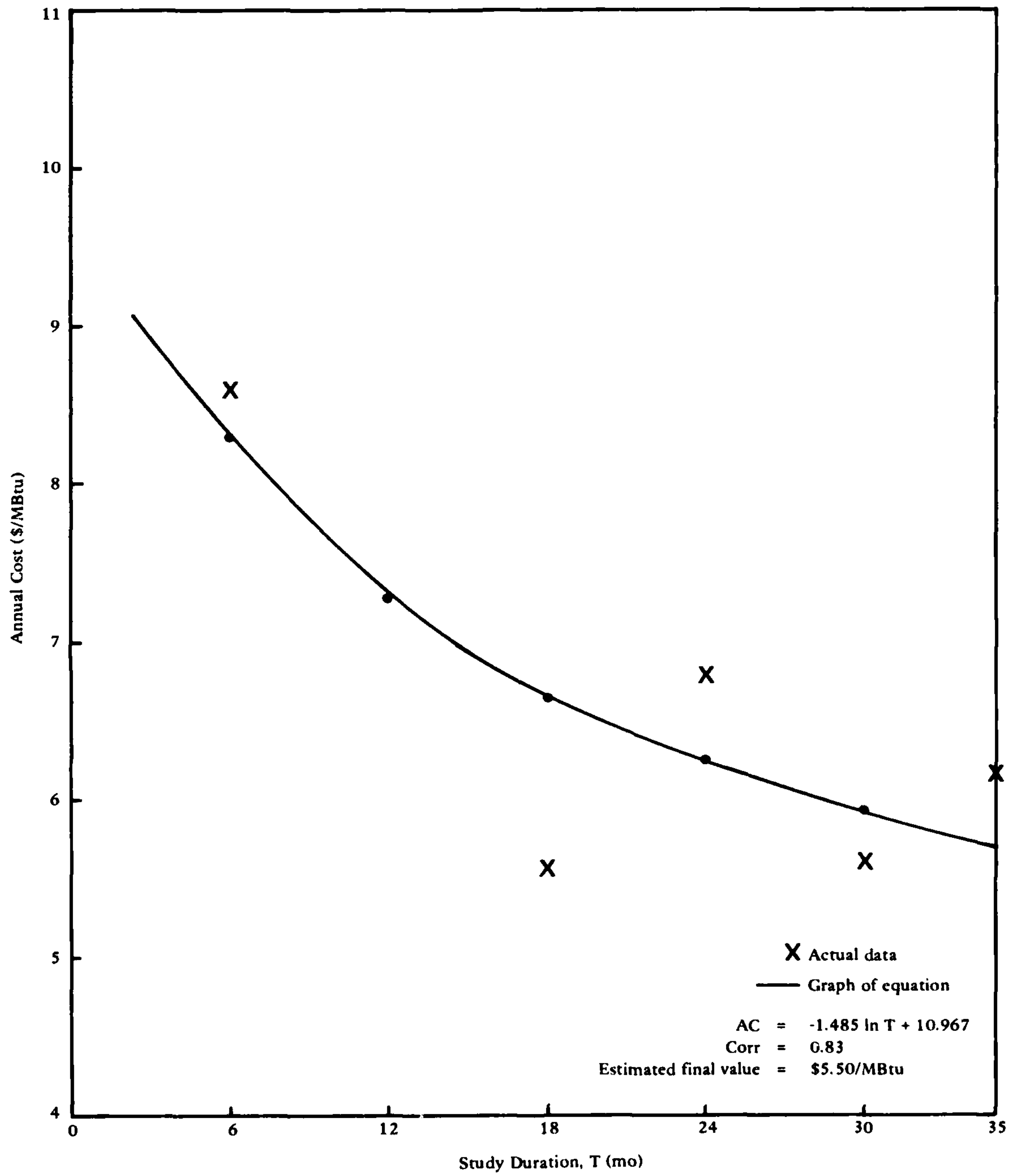


Figure 12. Steam cost over the study period.

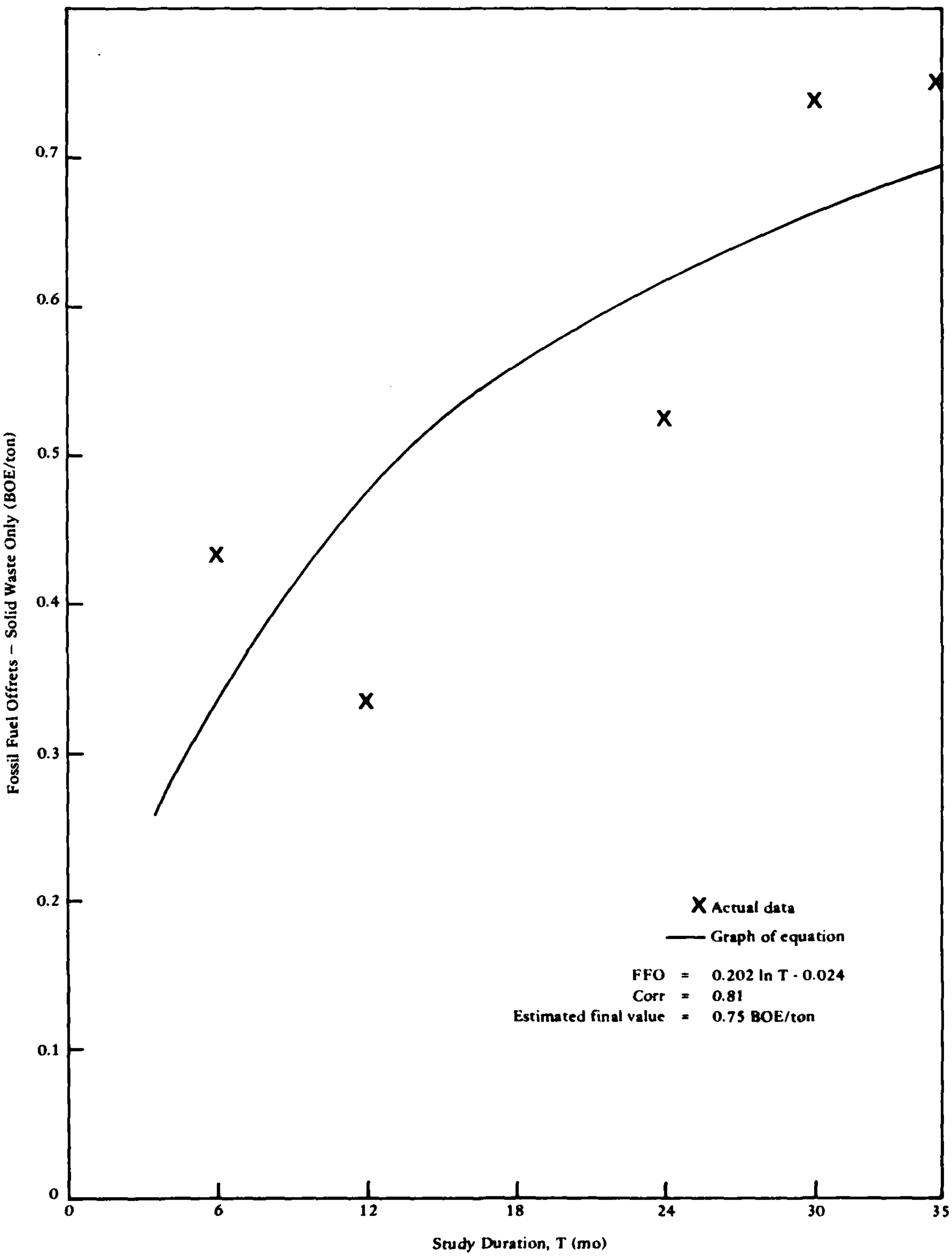


Figure 13. Fossil fuel offrets over the study period.

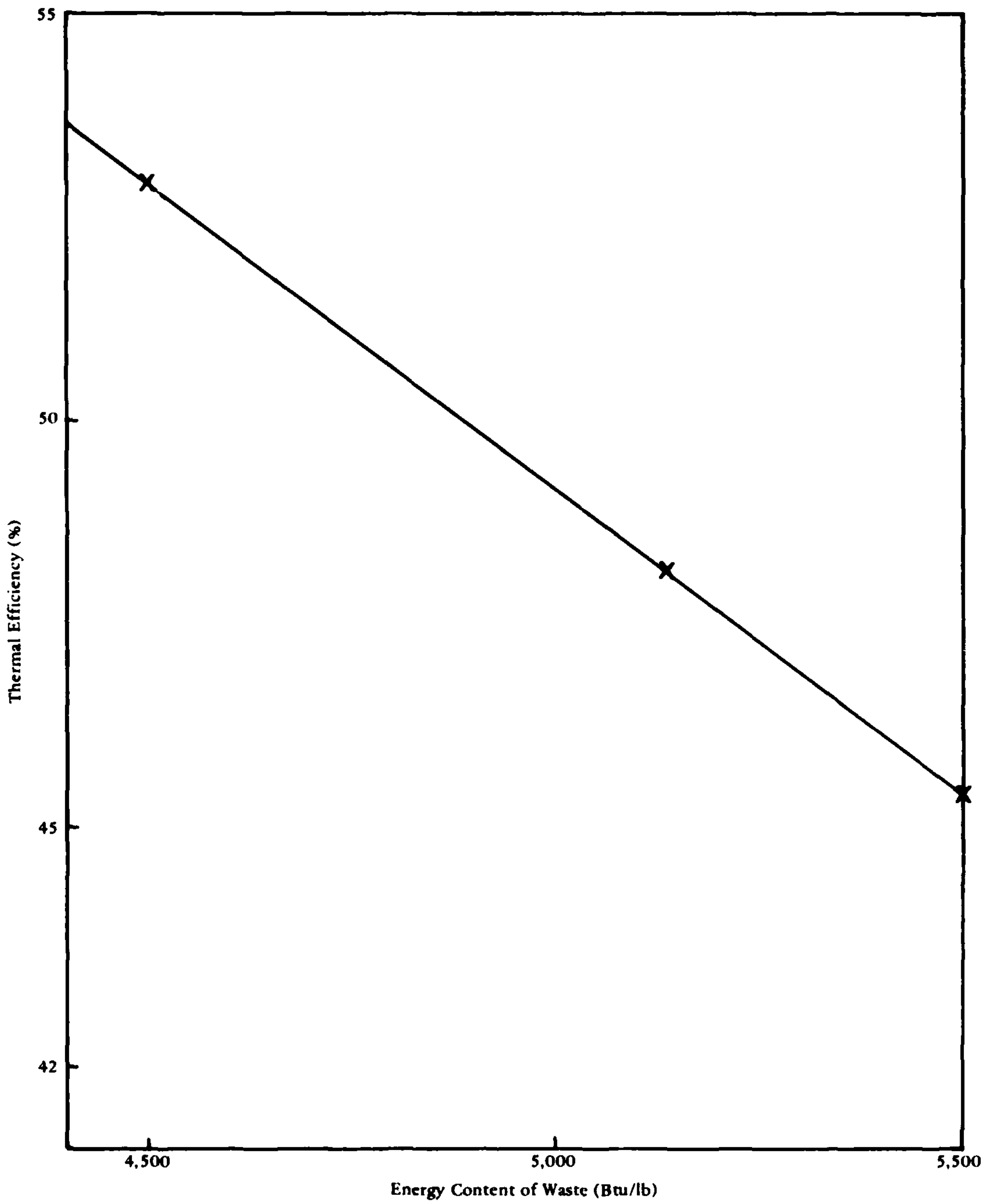


Figure 14. Variation in thermal efficiency versus waste energy content.

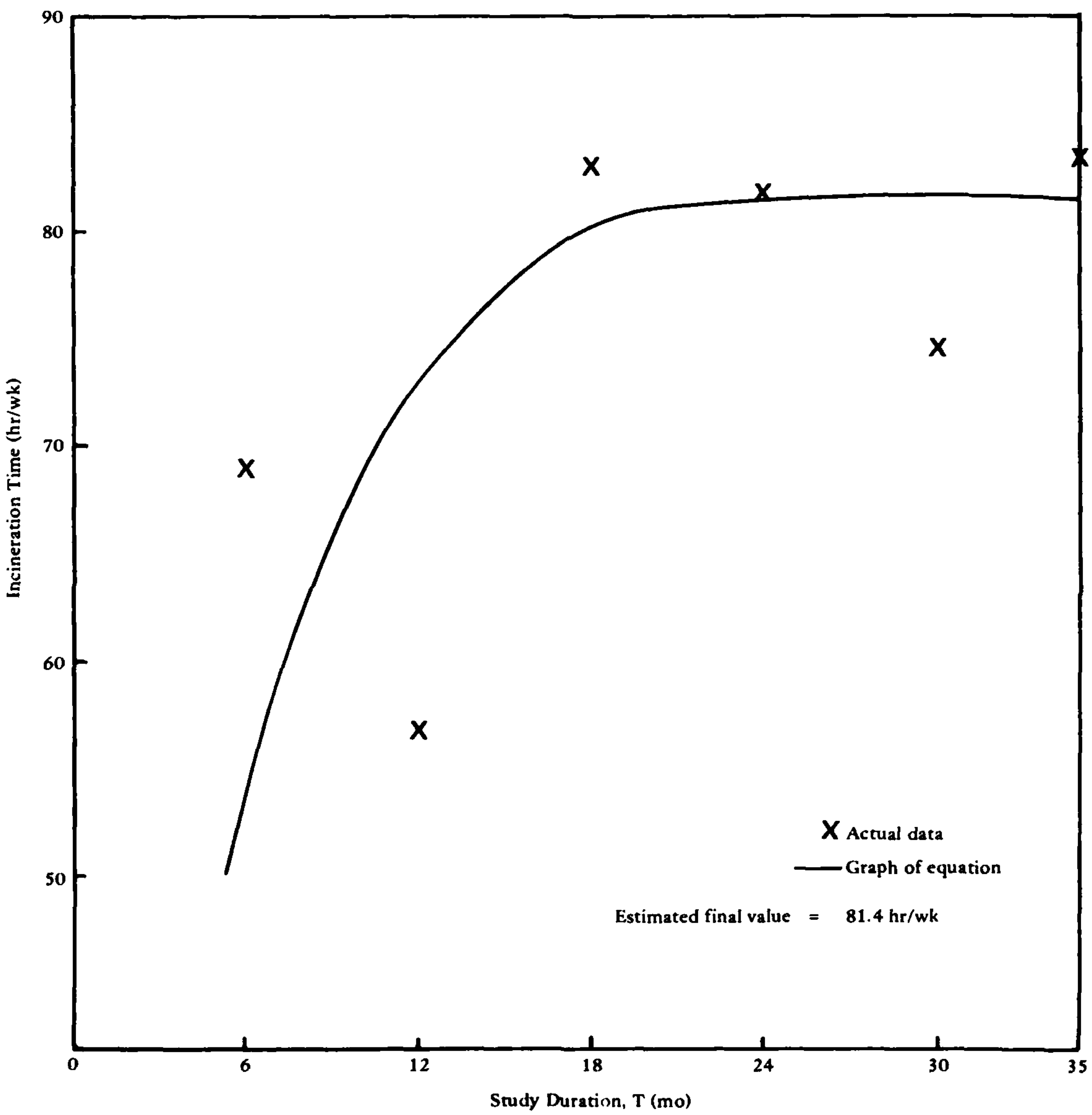


Figure 15. Incineration time over the study period.

Appendix A

JULY 1982 TO AUGUST 1983 (FY83) DATA ANALYSIS

SUMMARY

The following parameters were the result of the long-term evaluation of the heat recovery incinerator at Naval Station, Mayport, Fla., for the period from July 1982 to August 1983 (FY83).

Reliability, Availability, Maintainability

Mission No.	Mission Description	R^a	A_o	MTBF[b] (hr)	MTBMA (hr)	No. of Failures	No. of Other Actions	Total No. of Maintenance Actions
1	Incinerate and produce steam with solid waste	0.502	0.762	174	143	28	6	34
2	Incinerate solid waste only	0.554	0.762	203	162	24	6	30
3	Produce steam with or without solid waste	0.905	0.875	1,196	1,196	5	0	5

[a]Based on a 120-hour mission.
[b]Based on an operating time of 4,873 hours.

Overall HRI System Parameters

Parameters	Values
Thermal Efficiency (TE)	0.49
Specific Total Man-hours (STM)	0.397 man-hr/MBtu
Average Cost of Steam (ACS)	$6.54/MBtu
Percentage Landfill Reduction (PLR)	66%
Fuel Oil/Ton of Waste	29 gal/ton
Solid Waste Processing Rate (PR)	1.59 ton/hr

Breakdown of Time Categories

First column of numbers was for Mission 1 and 2 times, second column of numbers was for Mission 3 times (when waste oil was used to produce steam).

	Hours Involved	
Use of Time	Mission 1 and 2	Mission 3
Time spent operating the HRI (t_a)	4,873	5,982
Time spent in active preventive maintenance (t_b)	400	400
Time spent in active corrective maintenance (t_c)	289	34
Time the HRI was idle, but operational (t_d)	3,623	3,175
Time the HRI was idle, but not operational (t_e)	829	422

BACKGROUND

The data were collected and analyzed to determine RAM parameters for the three individual missions of the HRI: Mission 1, produce steam through the incineration of solid waste; Mission 2, incinerate solid waste without steam production; and Mission 3, produce steam firing waste oil and/or solid waste.

Performance of the first mission required that all of the HRI subsystems (receiving, incineration, ash, and boiler) be operational. The second mission needed to have all subsystems but the boiler operational. The third mission was operational as long as the boiler and incinerator - minus stoker and tuyere failures - were working.

The missions were necessary to evaluate performance in the three possible operational modes of the HRI. Table A-1 lists the RAM parameters for the three missions. Table A-2 totals the failures that occurred for each mission.

Mission 1 and 2 operational times were the same. The HRI did not incinerate solid waste unless it was producing steam. Mission 3 times were determined by adding the times that waste oil was used to produce steam to the operational time (t_a) of the boiler. To keep the time categories balanced with real time, the time added to t_a for Mission 3 had to be subtracted from t_c, t_d, and t_e as listed below:

t_c factor: -254.75 hr

t_d factor: -448.42 hr

t_e factor: <u>-406.65</u> hr

add to t_a: 1,109.82 hr

Two other anomalies affected the results of this study. First, from 4 October 1982 to 24 January 1983 no data on wet ash, fly ash, or reject weights were recorded due to various mechanical problems. Therefore, the solid waste incinerated data during this period were not used for long-term disposal parameters DR and PLR (Equations A-43 and A-44). Second, from 16 to 31 May 1983, the HRI was shut down for an overhaul. This time was not included in the analysis as the overhaul occurred only once in 3 years. Inclusion of the data from this period would distort the long-term performance averages. A more reasonable analysis was obtained by viewing HRI operation as 3 years at the predicted performance, then 2 weeks of overhaul.

FY83 HRI PERFORMANCE PROFILE

This section provides a summary of the data collected and the resulting RAM, thermal efficiency, and cost parameters for the NS Mayport HRI installation during the period between July 1982 and August 1983. This period was selected because the previous data had been reported in References 10 and 11.

Table A-3 provides the totals of the various times, fuel, water and waste consumed, and the steam produced during the period. The parameters represent the information for 432 calendar days and 295 operating days. Of the total possible hours, the HRI installation spent 5,982 hours operating, 434 hours in maintenance (both routine and corrective), 3,597 hours of idle time (operational and nonoperational combined), and 15 days (360 hours) in HRI overhaul (not used in analysis). The idle time was made up mostly of weekends and holidays when the HRI did not run. Under normal operating conditions, the HRI was idle from midnight Friday night until midnight Sunday night with approximately 7.5 hours of that time spent in scheduled maintenance. A monthly breakdown of all time and energy consumption categories is contained in Tables A-4 and A-5.

Table A-6 provides the detailed listing of the maintenance actions that were performed on the HRI. A maintenance action included any task that required the replacement of a failed component, adjustment or unjamming of an item, or any other action necessary to restore the HRI to full operation. The 34 maintenance actions included 28 failures. The most frequent problem areas included the overhead crane (seven maintenance actions, including six failures) and the incinerator feed ram hydraulic cylinder (14 maintenance actions, including 12 failures).

The long-term operational and solid waste disposal parameters are shown in Table A-7.

The demonstrated mean time between failure (MTBF) for the entire HRI installation was 174 hours. This means that on the average one would expect to operate for 174 hours before a failure-induced shutdown.

The demonstrated mean time between maintenance actions (MTBMA) for the entire HRI installation was 143 hours. This means that on the average one would expect to operate 143 hours and then require a maintenance action. Maintenance actions included all corrective actions (i.e., to replace a failed item or to unjam an item), including when a failure occurred.

The demonstrated Mission 1 reliability (R) for the entire HRI installation was 0.502. This means that there is a 0.502 probability that the HRI will operate trouble-free for 120 consecutive hours during a normal operation cycle.

The demonstrated Mission 1 operational availability (A_o) for the entire HRI installation was 0.762. This means that there is a 0.762 probability that the HRI will be capable of performing all of its functions when called upon at any random point in time.

There were 28 repairs associated with total HRI shutdowns that were used in the mean time to repair (MTTR) computations that accounted for 289 calendar hours. The demonstrated MTTR for HRI failure during this period was 10.3 hours (Table A-1). Twenty-four failures were repaired while the HRI was burning waste oil only to produce steam. This indicates that on the average approximately 10.3 hours (more than a complete shift) were required to restore the HRI to operation after a failed condition. A brief discussion of each subsystem's maintenance problems follows.

Incineration Subsystem. MTTR = 2.8 hours (two failures). The incinerator subsystem improved from FY82; only two minor failures occurred (stoker cylinder seal leak and a crack in the hopper cooling throat).

Receiving Subsystem. MTTR = 10.4 hours (22 failures). This subsystem consisted of the front-end loader, overhead crane, hopper, and incinerator ram feed. Six of the 22 subsystem failures were experienced by the overhead crane with repair times ranging from 3.3 to 40 hours. Twelve of the 22 subsystem failures were experienced by the feed ram with repair times ranging from 2 to 20 hours. The decrease in processing performance from FY82 to FY83 was due to the ram failures (12 versus zero in FY82). The most probable causes were that a failure in the feed ram guide wheels and ram misalignment caused an increase in hydraulic pressure in the ram cylinder. The same problem occurred in FY81 with four failures.

Boiler and Ash Removal Subsystems. MTTR = 10.6 (four failures). The 10.6-hour MTTR for the boiler subsystem was heavily influenced by 28 hours of repair time to rewind and restore the I.D. fan motor.

Ash Removal Subsystem. No failures occurred.

MAINTENANCE, THERMAL EFFICIENCY, AND COST PARAMETERS

The preventive maintenance ratio (PMR) was determined by dividing the man-hours spent on preventive maintenance by the total operating time. The PMR during this period was 0.175. This means that for every 24 hours of operation, 4.2 man-hours were required for routine preventive maintenance.

The corrective maintenance ratio (CMR) was determined by dividing the man-hours spent on corrective maintenance by the total operating time. The CMR was 0.034. This meant that for every 24 hours of operation, 0.8 man-hours were required for corrective maintenance.

The maintainability index (MI), which is the sum of PMR and CMR, was 0.209. This means that for every 24 hours of operation, 5 man-hours were spent on corrective and preventive maintenance.

The fossil fuel offsets were 9,147 BOE, while overall thermal efficiency for the HRI was 0.49. This means that for every Btu entering the HRI in the form of solid waste, kilowatt hours, and fuel oil, a little less than 1/2 Btu was released in the form of steam.

Thermal efficiency was determined by dividing the Btu output of the steam produced by the total quantity of solid waste and fuel oil Btu's supplied to the HRI. Sixty-four percent of the Btu's used in the HRI facility were derived from solid waste and another 24% were obtained from waste oil (which burned at 50 gph when solid waste was not being used). Electrical power provided 9% and the remaining 3% were acquired from make-up water, diesel fuel, and other fuel oil resources. The electrical power and diesel fuel data were extrapolated based on a short-term HRI test (Ref 13).

In calculating the average cost of steam (Equation A-38), it appears to have cost $6.54 to produce 1,000,000 Btu's of heat. This equation took into account the cost of repair and replacement parts, consumable items (e.g., water treatment chemicals, fuel, etc.) and labor costs but not capital costs. Only direct labor costs were considered and were based on an estimate of $10/hr.

CALCULATIONS

The calculations for the various parameters contained in Table A-1 used the equations detailed as follows. Additional manipulation of the data was required to provide the desired RAM, thermal efficiency (TE), and cost parameters. All numbers used in the RAM calculations were obtained directly from Tables A-4 and A-5; energy contents of the various energy sources used in the TE calculations were obtained from Reference 3 and standard thermodynamics tables; and the numbers used in the cost-factor calculations were obtained from documents supplied by the HRI contractor and affiliated Public Works Departments.

RAM Equations

Three separate values for reliability (R), maintainability (MI), and availability (A_o) parameters were developed to represent the three missions of the HRI. The following equations were used to compute the RAM parameters based upon data extracted from Tables A-4 and A-5.

1. $$MTBF = \frac{t_a}{N_f}$$

where: MTBF = mean time between failures, hr

t_a = operating time for the specific mission, hr

N_f = number of failures (see Table A-2)

$$MTBF_1 = \frac{4873}{28} = 174 \text{ hr} \qquad \text{(A-1)}$$

$$MTBF_2 = \frac{4873}{24} = 203 \text{ hr} \qquad \text{(A-2)}$$

$$MTBF_3 = \frac{5982}{5} = 1196 \text{ hr} \qquad \text{(A-3)}$$

2. $$MTBMA = \frac{t_a}{N_{ma}}$$

where: MTBMA = mean time between maintenance actions, hr

t_a = operating time for the specific mission, hr

N_{ma} = number of maintenance actions (see Table A-2)

$$MTBMA_1 = \frac{4873}{34} = 143 \text{ hr} \qquad \text{(A-4)}$$

$$MTBMA_2 = \frac{4873}{30} = 162 \text{ hr} \qquad \text{(A-5)}$$

$$MTBMA_3 = \frac{5982}{5} = 1196 \text{ hr} \quad \text{(A-6)}$$

3. $R = e^{-\lambda t_m}$

where: R = Reliability, decimal

e = Naperian base, 2.718

λ = failure rate for specific mission, 1/MTBF

t_m = mission time, 120 hr

$$R_1 = e^{-120/174} = 0.502 \quad \text{(A-7)}$$

$$R_2 = e^{-120/203} = 0.554 \quad \text{(A-8)}$$

$$R_3 = e^{-120/1196} = 0.905 \quad \text{(A-9)}$$

4. $$A_o = \frac{t_a}{t_a + t_b + t_c + t_e}$$

where: A_o = operational availability, decimal

t_a = operating time, hr

t_b = time spent in routine maintenance, hr

t_c = corrective maintenance for the specific mission, hr

t_e = idle, nonoperational time for the specific mission, hours

$$A_{o1} = \frac{4873}{4873 + 400 + 289 + 829} = 0.762 \quad \text{(A-10)}$$

$$A_{o2} = \frac{4873}{4873 + 400 + 289 + 829} = 0.762 \quad \text{(A-11)}$$

$$A_{o3} = \frac{5982}{5982 + 400 + 34 + 422} = 0.875 \quad \text{(A-12)}$$

5. $$MTTR = \frac{t_c}{N_r}$$

where: MTTR = mean time to repair, hr

t_c = corrective maintenance time, hr

N_r = number of repairs

$$MTTR = \frac{289}{28} = 10.3 \text{ hr} \tag{A-13}$$

6. $$PMR = \frac{Mt_b}{t_a}$$

where: PMR = preventive maintenance ratio, man-hr/hr

t_a = operating time, hr

Mt_b = labor spent on routine maintenance, man-hr

$$PMR = \frac{850.5}{4873} = 0.175 \text{ man-hr/hr} \tag{A-14}$$

7. $$CMR = \frac{Mt_c}{t_a}$$

where: CMR = corrective maintenance ratio, man-hr/hr

t_a = operating time, hr

Mt_c = labor spent on corrective maintenance, man-hr

$$CMR = \frac{166.5}{4873} = 0.034 \text{ man-hr/hr} \tag{A-15}$$

8. $$MI = \frac{Mt_b + Mt_c}{t_a}$$

where: MI = maintainability index, man-hr/hr

Mt_b = labor spent on preventive maintenance, man-hr

Mt_c = labor spent on corrective maintenance, man-hr

t_a = operating time, hr

$$MI = \frac{850.5 + 1665}{4873} = 0.209 \text{ man-hr/operating hr} \qquad \text{(A-16)}$$

Thermal Efficiency Equations

The equations for thermal efficiency utilize the data from Table A-5.

$$TE = \frac{M_{15} \times h_s}{H_{hri}}$$

$$= \frac{46,453,945 \times 1,185 \text{ Btu/lb}}{11.308 \times 10^{10} \text{ Btu}} = 0.49 \qquad \text{(A-17)}$$

where: TE = thermal efficiency, decimal

M_{15} = steam generated, lb

h_s = enthalpy of steam, Btu/lb

H_{hri} = energy supplied to HRI, Btu

H_{hri} was determined by the addition of the various energy resources supplied directly to the HRI. Equations A-18 through A-22 provide the individual computation of energy from the various resources, and Equation A-23 provides the computation of H_{hri}. In simplified form,

$$H_{hri} = H_{sw} + H_{vo} + H_{wo} + H_w \qquad \text{(A-18)}$$

where: H_{hri} = energy supplied to the HRI, Btu

H_{sw} = energy derived from solid waste and supplied to HRI, Btu

H_{fo} = energy derived from fuel oil and supplied to HRI, Btu

H_{wo} = energy derived from waste oil and supplied to HRI, Btu

H_w = energy derived from make-up water, Btu

1. Energy derived from solid waste:

$$H_{sw} = (h_{sw})(M_{12}) \tag{A-19}$$

$$= (5,134 \text{ Btu/lb})(2,000 \text{ lb/ton})(7,750.36 \text{ tons})$$

$$= 7.958 \times 10^{10} \text{ Btu}$$

where: H_{sw} = energy from solid waste, Btu

h_{sw} = higher heating value of solid waste (Ref 13), Btu/lb

M_{12} = solid waste supplied to HRI, ton

2. Energy derived from fuel oil:

$$H_{fo} = (h_{fo})(M_{20}) \tag{A-20}$$

$$= (138,810 \text{ Btu/gal})(502 \text{ gal})$$

$$= 6.968 \times 10^{7} \text{ Btu}$$

where: H_{fo} = energy from fuel oil, Btu

h_{fo} = higher heating value of fuel oil, Btu/gal

M_{20} = fuel oil supplied to HRI, gal

3. Energy derived from waste oil:

$$H_{wo} = (h_{wo})(M_{21}) \tag{A-21}$$

$$= (134,957 \text{ Btu/gal})(226,348 \text{ gal})$$

$$= 3.055 \times 10^{10} \text{ Btu}$$

where: H_{wo} = energy from waste oil, Btu

h_{wo} = higher heating value of waste oil, Btu/gal

M_{21} = waste oil supplied to HRI, gallons

4. Energy derived from make-up water

$$H_w = (h_w)(M_{17})(d_w) \tag{A-22}$$

$$= 48 \text{ Btu/lb} \times 7{,}234{,}000 \text{ gal} \times 8.3 \text{ lb/gal}$$

$$= 0.288 \times 10^{10} \text{ Btu}$$

where: H_w = energy derived from make-up water, Btu

h_w = enthalpy of the make-up water, Btu/lb

M_{17} = quantity of make-up water, gal

d_w = density of make-up water, lb/gal

Therefore:

$$H_{hri} = 7.958 \times 10^{10} \text{ Btu} + 0.007 \times 10^{10} \text{ Btu} \tag{A-23}$$

$$+ 3.055 \times 10^{10} \text{ Btu} + 0.288 \times 10^{10} \text{ Btu}$$

$$= 11.308 \times 10^{10} \text{ Btu}$$

Fossil Fuel Offsets

Fossil fuel offsets were used to determine the potential energy savings from incinerating solid waste. Fossil fuel offsets were calculated by subtracting the quantity of fossil fuels (fuel oil, electricity, and front-end loader diesel fuel) consumed by the HRI from the quantity of fossil fuels saved by the HRI. The fossil fuels saved are equal to the steam energy produced by the HRI divided by boiler thermal efficiency. This information is expressed in equations A-24 through A-28.

1. Fossil fuel energy saved:

$$FF_B = \frac{M_{15} \times h_s}{TE_B} \tag{A-24}$$

$$= \frac{46{,}453{,}945 \text{ lb} \times 1{,}185 \text{ Btu/lb}}{0.80}$$

$$= 6.881 \times 10^{10} \text{ Btu}$$

where: M_{15} = quantity of steam produced, lb

h_s = enthalpy of steam, Btu/lb

TE_B = boiler thermal efficiency

2. Energy equivalent of electrical power supplied to the HRI:

$$E_t = (e_t)(T_{kwh})(t_a) \qquad \text{(A-25)}$$

$$= (11{,}600)(169.31)(5982)$$

$$= 1.175 \times 10^{10} \text{ Btu}$$

where: E_t = electrical energy supplied to the HRI, Btu

e_t = conversion factor, Btu/kW-hr

T_{kWh} = average kW-hr supplied to the HRI/operating hour, from short-term test at NS Mayport (Ref 13), kW-hr/hr

t_a = operating time of the HRI, hr

3. Energy derived from front-end loader:

$$H_{df} = (h_{df})(M_{22}) \sim (h_{df})(M_{12}) \qquad \text{(A-26)}$$

$$= (58{,}725 \text{ Btu/ton})(7{,}750.36 \text{ tons})$$

$$= 0.046 \times 10^{10} \text{ Btu}$$

where: H_{df} = energy from front-end loader diesel fuel, Btu

h_{df} = higher heating value from diesel fuel, estimated value based on information given by plant personnel and same duty cycle as FY81 (Ref 10), 58,725 Btu per ton of solid waste (Ref 10)

M_{22} = fuel supplied to front-end loader, not measured, gal

M_{12} = solid waste supplied to HRI, ton

4. Fossil fuel consumed - HRI:

$$FF_H = H_{fo} + E_t + H_{df} + H_w \qquad \text{(A-27)}$$

$$= 0.007 \times 10^{10} + 1.175 \times 10^{10} + 0.046 \times 10^{10} + 0.288 \times 10^{10} \text{ Btu}$$

$$= 1.576 \times 10^{10} \text{ Btu}$$

where: FF_H = fossil fuels consumed by the HRI, Btu

H_{fo} = energy derived from fuel oil, Btu

E_t = energy derived from electricity, Btu

H_{df} = energy derived from diesel fuel, Btu

H_w = energy of make-up water, Btu

5. Fossil fuel offset:

$$FFO = \frac{FF_B - FF_H}{CF_{FFO}} \qquad \text{(A-28)}$$

$$= \frac{6.881 \times 10^{10} - 1.576 \times 10^{10} \text{ Btu}}{5.8 \times 10^6 \text{ Btu/BOE}}$$

$$= 9{,}147 \text{ BOE}$$

where: FFO = fossil fuel offsets, BOE

FF_B = fossil fuel used by the boiler, Btu

FF_H = fossil fuel used by the HRI, Btu

C_{FFO} = conversion factor, Btu to BOE, 5.8×10^6

Cost Equations

The equations for cost were solved using information from Tables A-4 and A-5.

$$SOM = \frac{M_{ta} \times 10^6}{M_{15} \times h_s - H_w} \qquad \text{(A-29)}$$

$$= \frac{19,696 \times 10^6}{5.2168 \times 10^{10}}$$

$$= 0.3776 \text{ man-hr/MBtu}$$

where: SOM = specific operating man-hours, man-hr/MBtu

Mt_a = labor spent operating the HRI, man-hr

M_{15} = total quantity of steam produced, lb

h_s = enthalpy of the steam, 1,185 Btu/lb

H_w = energy of the make-up water at 80°F, Btu

$$SRM = \frac{(Mt_b + Mt_c) \times 10^6}{M_{15} \times h_s - H_w} \qquad \text{(A-30)}$$

$$= \frac{1,017 \times 10^6}{5.2818 \times 10^{10}}$$

$$= 0.0195 \text{ man-hr/MBtu}$$

where: SRM = specific repair and maintenance man-hours, manhr/MBtu

Mt_b = labor spent in preventive maintenance, man-hr

Mt_c = labor spent in corrective maintenance, man-hr

M_{15} = total quantity of steam produced, lb

h_s = enthalpy of steam, 1,185 Btu/lb

H_w = energy of make-up water at 80°F, Btu

$$STM = SOM + SRM \qquad \text{(A-31)}$$

$$= (0.3776 + 0.0195)$$

$$= 0.3971 \text{ man-hr/MBtu}$$

where: STM = specific total man-hours, man-hr/MBtu

SOM = specific operating man-hours, man-hr/MBtu

SRM = specific repair and maintenance man-hours, man-hr/MBtu

$$SRC = \frac{CP \times 10^6}{M_{15} \times h_s - H_w} \tag{A-32}$$

$$= \frac{\$1,220 \times 10^6}{5.2818 \times 10^{10}}$$

$$= \$0.023/\text{MBtu}$$

where: SRC = specific repair and maintenance cost, \$/MBtu

CP = total cost of parts used in repairs/replacements and maintenance, \$

h_s = steam enthalpy, Btu/lb

M_{15} = total quantity of steam produced, lb

H_w = energy of make-up water, Btu

$$SCC = \frac{(CF + CC)(10^6)}{M_{15} \times h_s - H_w} \tag{A-33}$$

$$= \frac{\$132,892 \times 10^6}{5.2818 \times 10^{10}}$$

$$= \$2.55/\text{MBtu}$$

where: SCC = specific consumable costs, \$/MBtu

CF = total cost of fuel used (fuel and waste oil, diesel and electrical power), \$

CC = total cost of consumable supplies not included in CF, \$

h_s = enthalpy of steam, Btu/lb

M_{15} = total quantity of steam produced, lb

H_w = energy of make-up water, Btu/lb

The breakdown in costs and quantities used for the 14-month operation is as follows:

1. Water treatment chemicals:

Salt = (39,960 lb)($2.60/80 lb) = $1,299 (A-34)

PO_4 = (770.75 lb)($50.64/100 lb) = $390 (A-35)

SO_3 = (870.5 lb)($29.36/100 lb) = $256 (A-36)

Subtotal $1,945

2. Electrical power:

1 kW-hr = $0.06

E_T = (169.31 kW/hr x 5,982 hr)($0.06/kW) (A-37)
= $60,769

where E_T = electrical cost, $

3. Waste oil:

226,348 gal consumed @ $0.30/gal

Cost for waste oil = (226,348 gal)($0.30/gal) (A-38)
= $67,904

4. Fuel oil:

502 gal consumed @ $1.12/gal

Cost for fuel oil = (502 gal)($1.12/gal) (A-39)
= $562

5. Diesel fuel:

0.181 gal/ton (Ref 10) x 77,500.36 tons

1,403 gal consumed @ \$1.22/gal

$$\text{Cost for diesel fuel} = (1{,}403\ \text{gal})(\$1.22/\text{gal}) = \$1{,}712 \qquad \text{(A-40)}$$

6. Other consumables (e.g., hydraulic fluid, refractory):

Cost = \$0.00

7. Total:

Total cost of items 1 through 6 = \$132,892

$$\begin{aligned} ACS &= SRC + SCC + (STM \times W) \qquad \text{(A-41)} \\ &= 0.03 + 2.55 + 0.3971 \times 10 \\ &= 6.54/\text{MBtu} \end{aligned}$$

where: ACS = average cost of steam, \$/MBtu

SRC = specific cost of repairs and maintenance, \$/MBtu

SCC = specific cost of consumables, \$/MBtu

STM = specific total man-hours, man-hr/MBtu

W = wages (based on an estimate derived from Public Works job orders of \$10/hr), \$/hr

Operational Performance Parameters

The incineration rate and steam production were two parameters that could be used to determine operational performance. These parameters were determined by the following equations.

$$IR = \frac{M_{12}}{t_i} = \frac{7{,}750}{4{,}873} = 1.59\ \text{TPH} \qquad \text{(A-42)}$$

where: IR = incineration rate of the HRI facility, ton/hr

M_{12} = solid waste burned in the HRI, ton

t_i = incineration equipment operation time, hr

$$SP = \frac{M_{15} \times h_s - (H_{FO} + H_{WO}) \times TE_{WO} - H_w}{M_{12} \times h_s} \qquad \text{(A-43)}$$

$$= \frac{46{,}453{,}945 \text{ lb}(1{,}185 \text{ Btu/lb}) - (0.007\text{x}10^{10} + 3.055\text{x}10^{10})(0.63) - 0.288\text{x}10^{10} \text{ Btu}}{(7{,}750)(2{,}000 \text{ lb/ton})(1{,}185)}$$

= 1.79 lb steam/lb solid waste

where: SP = efficiency of steam production, lb of steam/lb of solid waste

M_{12} = solid waste supplied to HRI, ton

E_{sw} = steam energy produced from solid waste, Btu

h_s = enthalpy of steam, Btu/lb

H_w = energy of make-up water, Btu

Solid Waste Disposal Efficiency

The efficiency of the HRI facility in reducing the volume of solid waste that would otherwise be delivered to the landfill was determined by the following equations.

$$DR = \frac{M_{12} - M_{14}}{M_{12}} \qquad \text{(A-44)}$$

$$= \frac{5{,}611 - 1{,}738 \times 100}{5{,}611}$$

= 69%

where: DR = efficiency of solid waste weight reduction through incineration, %

M_{12} = solid waste burned in the HRI, ton*

M_{14} = wet ash removed, ton*

From July 1982 to August 1983, the total amount of solid waste delivered to the plant was 5,844.83 tons. The total sent to the landfill was 1,993.73 tons. Therefore, the percentage of landfill reduction (PLR) for this period was:

$$PLR = 100 \times 1 - \frac{(M_3 + M_{14} + M_a)}{M_3 + M_{12}} \tag{A-45}$$

$$= 100 \times 1 - \frac{(233.60 + 1,738.33 + 21.80)}{233.60 + 5,611.23}$$

$$= 100 \times 1 - \frac{1,993.73}{5,844.83}$$

$$= 66\%$$

where: PLR = landfill reduction by weight, %

M_3 = quantity of solid waste rejected by hand, ton*

M_{12} = quantity of solid waste incinerated, ton*

M_a = quantity of fly ash and slag, ton*

M_{14} = quantity of wet ash removed, ton*

The quantity of waste delivered to the HRI minus the quantity of waste taken from the HRI provided a gross index for landfill savings accomplished by incineration. For the 14-month period, this number was: 5,844.83 - 1,993.73 = 3,851.10 tons*.

Time Categories

During the evaluation and extraction of data, manipulation of the reported time categories was required to provide the proper increments of time necessary to compute the various RAM parameters. This was particularly true during periods of downtime when both corrective and

*For a 16-week period, no weight information was provided. Therefore, the waste delivered during this period was not counted in the total waste categories.

preventive (routine) maintenance were performed. The reported data did not always indicate when such maintenance started and stopped during long periods of shutdown. It was often implied that the entire 24-hour period was spent performing both corrective and preventive maintenance. The data from such scenarios were modified using the following criteria. Ten hours out of each 24-hour downtime cycle were estimated as being spent on actual corrective maintenance (t_c) and the remaining 14 hours logged as HRI idle, but not operational (t_e). The resulting time categories are reflected in Table A-4. This technique provided the desired sensitivity to ensure more realistic RAM data.

During these lengthy shutdowns for corrective maintenance, the three shifts performed preventive maintenance, that is, procedures that were desirable, but not required. The logs reflected this approach to preventive maintenance during these shutdown periods. To correctly solve the time equation for the HRI operation listed below, the time categories could not overlap. Therefore, when the system was shutdown for corrective maintenance and some preventive maintenance was performed concurrently, the time was charged only to corrective maintenance.

$$T = t_a + t_b + t_c + t_d + t_e = 10{,}014 \text{ hr} \tag{A-46}$$

where: T = 14-month HRI monitoring period (not including 15 days of HRI overhaul time)

t_a = operating period, hr

t_b = calendar time spent on routine maintenance, hr

t_c = calendar time spent on repairs/replacement, hr

t_d = idle time, HRI operational, hr

t_e = idle time, HRI not operational, hr

Table A-1. NS Mayport HRI RAM, Thermal Efficiency, and Cost

Parameter	Value
1. Mean time between failures (MTBF), hr	
a. Incinerate and produce steam with solid waste ($MTBF_1$)	174
b. Incinerate solid waste ($MTBF_2$)	203
c. Produce steam without solid waste ($MTBF_3$)	1,196
2. Mean time between maintenance actions (MTBMA), hr	
a. Incinerate and produce steam with solid waste ($MTBMA_1$)	143
b. Incinerate solid waste ($MTBMA_2$)	162
c. Produce steam without solid waste ($MTBMA_3$)	1,196
3. Reliability (R)	
a. Incinerate and produce steam with solid waste (R_1)	0.502
b. Incinerate solid waste (R_2)	0.554
c. Produce steam without solid waste (R_3)	0.905
4. Operational availability (A_o)	
a. Incinerate and produce steam with solid waste (A_{o1})	0.762
b. Incinerate solid waste (A_{o2})	0.762
c. Produce steam without solid waste (A_{o3})	0.875
5. Mean time to repair (MTTR), hr	10.3
6. Preventive maintenance ratio (PMR), man-hr/operating hr	0.175
7. Corrective maintenance ratio (CMR), man-hr/operating hr	0.034

continued

Table A-1. Continued

Parameter	Value
8. Maintainability index (MI), man-hr/operating hr	0.209
9. Thermal efficiency (TE), %	0.49
10. Fossil fuel offsets (FFO), BOE	9,147
11. Specific operating man-hours (SOM), man-hr/MBtu	0.3776
12. Specific repair and maintenance (SRM), man-hr/MBtu	0.0195
13. Specific total man-hours (STM), man-hr/MBtu	0.3971
14. Specific repair and maintenance cost (SRC), $/MBtu	0.023
15. Specific consumable cost (SCC), $/MBtu	2.55
16. Average cost of steam (ACS), $/MBtu	6.54

Table A-2. Summary of NS Mayport HRI Maintenance Action Data

Item	Maintenance Action[a]		
	Failures	Other	Total
Equipment Affected			
1. Front-end loader, overhead crane, hopper, feed ram	22	3	25
2. Incinerator	2	0	2
3. Ash conveyor	0	3	3
4. Boiler, de-aerator, I.D. fan	4	0	4
Totals	28	6	34
Function Affected			
5. Incinerate and produce steam with solid waste (requires 1 through 4 above)	28	6	34
6. Incinerate solid waste (requires 1 through 3 above)	24	6	30
7. Produce steam without solid waste requires 2 and 4 above)	5[b]	0	5

[a]Maintenance actions equal failures plus others.

[b]Stoker failure removed from item 2 above for this function.

Table A-3. Summary of NS Mayport HRI Data

Five-Quarter FY83 Data Base	Value
Time Category	
1. Calendar time (incinerator and boiler) in operation, Mission 3 time	5,982 hr
2. Calendar time overhead crane, ash conveyor, and feed ram in operation	4,873 hr
3. Man-hours spent in operation	19,696 hr
4. Calendar time in corrective maintenance (Mission 3 time)	289 hr (34)
5. Man-hours spent in corrective maintenance	166 hr
6. Calendar time in routine maintenance	400 hr
7. Man-hours spent in routine maintenance	850 hr
8. Time HRI idle, but operational (Mission 3 time)	3,623 hr (3,175)
9. Time HRI idle, not operational (Mission 3 time)	829 hr (422)
Fuel, Water, Waste, Steam	
10. Waste oil consumed	226,348 gal
11. Fuel oil consumed	502 gal
12. Make-up water consumed	7,234,000 gal
13. Blowdown	-
14. Solid waste incinerated	7,750 tons
15. Solid waste rejected (hand-picked)	234 tons*
16. Wet ash	1,738 tons*
17. Fly ash	22 tons*
18. Steam produced	46,453,945 lb

*For a 16-week period, these values were not recorded; therefore, a reduced incinerated solid waste total was used in the data analysis.

Table A-4. Number of Hours and Man-hours Used in Analysis

Month	Operation Time, t_a (hr)	Routine Maintenance Time, t_b (hr)	Corrective Maintenance Time, t_c (hr)	Idle but Operational, t_d (hr)	Idle not Operational, t_e (man-hr)	Time in Operation, M_{ta} (man-hr)	Time in Routine Maintenance, M_{tb} (man-hr)	Time in Corrective Maintenance, M_{tc} (man-hr)
July	251.25	22	5.58	209.75	195.08	1,280	44	4.5
August	473.49	34.5	30	243.75	124.58	1,600	145	92
September	332.10	16.50	25.92	201.33	30.16	1,280	33	0
October	378.91	27.5	36	242	154.08	1,600	55	6
November	332	32	16	277.92	14	1,232	44	28
December	417.92	34.25	10	353.75	30.67	1,504	63.5	0
January	271.92	28	50	262.33	57.75	1,280	75	0
February	298.92	22.75	9.25	292.68	51.42	1,280	42.5	0
March	238.67	28	13.75	270.33	124	1,280	52	36
April	372.66	30.5	20	236	10.08	1,360	61	0
May	258.83	15	28.17	124.5	18	1,520	43.5	0
June	277.09	32	14.16	324.5	0	1,440	62	0
July	450	38	30	303.25	19.25	1,440	57	0
August	518.83	39	0	281.17	0	1,600	73	0
Totals	4,872.59	400	288.83	3,623.26	829.07	19,696	850.5	166.5

Table A-5. Energy Resources Consumed, Rejected, and Steam Outputs

[No useable data were available on blowdown, M_{19}.]

Month	Waste Fuel, M_{21} (gal)	Make-up Water, M_{17} (gal)	Solid Waste Incinerated, M_{12} (tons)	Rejected Solid Waste, M_3 (tons)	Wet Ash, M_{14} (tons)	Fly Ash, M_a (tons)	Steam Produced M_{15} (lb)	Virgin Oil M_{20} (gal)
July	18,359	470,500	501.63	19.49	137.33	1.96	2,367,400	0
August	29,674	739,300	663.42	28.05	144.38	2.25	3,862,000	0
September	18,946	510,100	307.33	18.42	132.57	2.12	2,471,400	10
October	22,317	613,600	592.02	5.44[a]	16.94[a]	0.57	3,886,900	0
November	17,628	527,500	496.85	0[a]	0[a]	0[a]	3,294,100	0
December	12,903	633,200	794.81	0[a]	0[a]	0[a]	4,302,000	0
January	23,752	560,400	486.56	7.69[a]	45.47[a]	0.40[a]	3,867,500	0
February	21,413	485,500	463.30	39.43	100.29	1.95	3,531,500	0
March	17,977	441,600	474.30	15.65	160.15	2.43	3,441,600	486
April	9,363	424,900	529.24	25.60	173.71	2.73	2,388,446	0
May	7,047	451,400	516.61	23.38	171.35	2.30	2,666,205	2
June	11,057	457,600	577.05	19.65	210.33	1.99	3,855,558	0
July	6,741	425,200	585.66	13.17	173.73	0.9	3,135,123	4
August	9,171	493,200	761.58	17.63	272.08	2.20	3,384,213	0
Total	226,348	7,234,000	7,750.36	233.60[a]	1,738.33[a]	21.80[a]	46,453,945	502

[a]Data not reported for part of period.

Table A-6. Summary of HRI Problem Events

Date	Class	Subsystem (Code)	Failed Equipment or Part
6/29/82	Failure	Incinerator	Rod seal on stoker grate failed
7/16/82	Failure	Incinerator	Crack in hopper throat
7/27/82	Maintenance	Ash	Ash chain jumped; bent flights
8/26/82	Failure	Boiler	I.D. fan motor burnt out
8/26/82	Failure	Receiving	Ram cylinder rod seal failed
9/7/82	Failure	Receiving	Crane cable broke
9/14/82	Failure	Receiving	Ram cylinder rod seal failed
9/15/82	Maintenance	Ash	Ash chain off sprockets
9/21/82	Failure	Receiving	Front-end loader broke
10/5/82	Failure	Receiving	Front-end loader broke
10/15/82	Failure	Boiler	Feedwater pump motor burned out
10/22/82	Failure	Receiving	Overhead crane broke
11/11/82	Failure	Receiving	Ram cylinder rod seal failed
11/11/82	Failure	Boiler	Check valve failed, low water in boiler; damaged tubes
11/24/82	Failure	Receiving	Front-end loader broke
11/29/82	Maintenance	Receiving	Overhead crane cable jammed
12/8/82	Failure	Receiving	Overhead crane broke
12/10/82	Maintenance	Ash	Ash chain off sprockets
1/11/83	Failure	Receiving	Overhead crane broke
1/25/83	Failure	Receiving	Ram cylinder rod seal failed

continued

Table A-6. Continued

Date	Class	Subsystem (Code)	Failed Equipment or Part
2/8/83	Maintenance	Receiving	Replaced faulty ram cylinder
2/11/83	Failure	Receiving	Ruptured "O" ring in ram cylinder
2/16/83	Maintenance	Receiving	Repairs made on ram cylinder
3/4/83	Failure	Receiving	Overhead crane broke
3/17/83	Failure	Receiving	Rod seal on ram cylinder failed
3/18/83	Failure	Boiler	I.D. fan bearings replaced
3/30/83	Failure	Receiving	Front-end loader broken
4/5/83	Failure	Receiving	Ram cylinder rod seal failed
4/27/83	Failure	Receiving	Electrical coil in crane burned out
5/5/83	Failure	Receiving	Ram cylinder rod seal failed
6/1/83	Failure	Receiving	Ram cylinder rod seal failed
6/17/83	Failure	Receiving	Ram cylinder rod seal failed
7/14/83	Failure	Receiving	Ram cylinder rod seal failed
7/20/83	Failure	Receiving	Ram cylinder rod seal failed

Table A-7. Parameters for Operational and Solid Waste Disposal

Item	Value
Incineration rate of the HRI facility, ton/hr	1.59
Steam production, lb of steam/lb of solid waste	1.79
Solid waste weight reduction through incineration, %	69
Landfill reduction (by weight) of solid waste accepted at HRI, %	66

Appendix B

OPERATIONAL PARAMETER CALCULATIONS

STEAM PRODUCTION

Steam per gallon of waste and fuel oils:

Steam produced by waste and fuel oils:

$$S_o = [(M_{20})(h_{fo}) + (M_{21})(h_{wo})]\ TE_{wo}/h_s$$

$$= [(1{,}820\ \text{gal})(138{,}810\ \text{Btu/gal}) + (520{,}239\ \text{gal})$$

$$(134{,}957\ \text{Btu/gal})] \times 0.63/1{,}185$$

$$= 37{,}461{,}091 \text{ pounds of steam from oil}$$

where: S_o = steam produced by waste and fuel oils, lb

M_{20} = quantity of fuel oil consumed, gal

h_{fo} = higher heating value of fuel oil, Btu/gal

M_{21} = quantity of waste oil consumed, gal

h_{wo} = higher heating value of waste oil, Btu/gal

TE_{wo} = efficiency of oil incineration

h_s = enthalpy of steam, Btu/lb

Steam/gallon:

$$R_o = \frac{S_o}{M_{20} + M_{21}} = \frac{37{,}461{,}091}{1{,}820 + 520{,}239} = 72 \text{ lb steam/gal}$$

where: R_o = rate of steam production from oil, lb/gal

S_o = steam produced by waste and fuel oils, lb

M_{20} = quantity of fuel oil consumed, gal

M_{21} = quantity of waste oil consumed, gal

Steam produced by solid waste:

Remove steam from oil and make-up water from the total steam produced:

$$S_{sw} = M_{15} - S_o - H_w/h_s$$

$$= 101{,}297{,}833 - 37{,}461{,}091 - 0.628 \times 10^{10}/1{,}185$$

$$= 58{,}537{,}164 \text{ lb steam}$$

where: S_{sw} = steam produced by solid waste, lb

M_{15} = total quantity of steam, lb

S_o = steam produced by waste and fuel oil, lb

H_w = energy from make-up water, Btu

h_s = enthalpy of steam, Btu/lb

Average steam per ton of waste:

$$R_{sw} = \frac{S_{sw}}{M_{12}} = \frac{58{,}537{,}164 \text{ lb}}{16{,}372.72 \text{ tons}} = 3{,}500 \text{ lb/ton of steam}$$

where: R_{sw} = rate of steam production from waste, lb/ton

S_{sw} = steam produced by solid waste, lb

M_{12} = quantity of waste incinerated, tons

SOLID WASTE THERMAL EFFICIENCY CALCULATIONS

Remove steam energy produced by waste and fuel oil from the total steam energy produced:

Waste oil energy:

$$E_{wo} = M_{21} \times h_{wo} \times TE_{wo}$$

$= 520{,}239 \text{ gal} \times 134{,}957 \text{ Btu/gal} \times 0.63$

$= 4.423 \times 10^{10}$ Btu of steam from waste oil

where: E_{wo} = steam energy from waste oil, Btu

M_{21} = quantity of waste oil consumed (Table 2), gal

h_{wo} = heating value of waste oil, Btu/gal

TE_{wo} = efficiency of waste oil incineration

Fuel oil energy:

$$E_{fo} = M_{20} \times h_{fo} \times TE_{wo}$$

$= 1{,}820 \text{ gal} \times 138{,}810 \text{ Btu/gal} \times 0.63$

$= 0.016 \times 10^{10}$ Btu of steam from fuel oil

where: E_{fo} = steam energy from fuel oil, Btu

M_{20} = quantity of fuel oil consumed (Table 2), gal

h_{fo} = heating value of fuel oil, Btu/gal

TE_{wo} = efficiency of fuel oil incineration

Make-up water energy:

$$H_w = M_{17} \times d_w \times h_w$$

$= 15{,}775{,}550 \text{ gal} \times 8.3 \text{ lb/gal} \times 48 \text{ Btu/gal}$

$= 0.628 \times 10^{10}$ Btu

where: H_w = make-up water energy, Btu

M_{17} = make-up water quantity, gal

d_w = make-up water density, lb/gal

h_w = make-up water enthalpy, Btu/lb

Subtract oil energy from total energy:

$$E_{sw} = M_{15} \times h_s - H_w - E_{wo} - E_{fo}$$
$$= 101{,}297{,}833 \text{ lb} \times 1{,}185 - 0.628 \times 10^{10} \text{ Btu}$$
$$- 4.423 \times 10^{10} \text{ Btu} - 0.016 \times 10^{10} \text{ Btu}$$
$$= 6.936 \times 10^{10} \text{ Btu from solid waste}$$

where: E_{sw} = steam energy from solid waste, Btu

M_{15} = quantity of steam produced, lb

h_s = enthalpy of steam, Btu/lb

H_w = energy of make-up water, Btu

E_{wo} = steam energy from waste oil, Btu

E_{fo} = steam energy from fuel oil, Btu

Thermal efficiency of solid waste incineration:

$$TE_{sw} = \frac{E_{sw}}{H_{sw}} = \frac{6.936 \times 10^{10} \text{ Btu}}{5{,}134 \text{ Btu/lb} \times 2{,}000 \text{ lb/ton} \times 16{,}372.72 \text{ tons}} = 0.41$$

where: TE_{sw} = efficiency of solid waste incineration

E_{sw} = steam energy from solid waste, Btu

H_{sw} = energy from solid waste incinerated, Btu

ANNUAL ENERGY COST SAVINGS CALCULATIONS

Projected steam energy produced per year:

$$S_{HRI} = [(R_o \times FR_o + R_{sw} \times IR) \times T_{sw} + T_o \times FR_{om} \times R_o] \times h_s$$
$$= [(72 \text{ lb/gal} \times 10 \text{ gal/hr} + 3{,}800 \text{ lb/ton} \times 1.75 \text{ ton/hr})$$
$$\times 81.4 \text{ hr/wk} + 7.4 \text{ hr/wk} \times 50 \text{ gal/hr} \times 72 \text{ lb/gal}] \times 52 \text{ wk/yr}$$
$$\times 1{,}185 \div 1 \times 10^6 \text{ Btu/MBtu}$$
$$= 38{,}610 \text{ MBtu/yr}$$

where: S_{HRI} = energy from steam produced by the HRI, MBtu

R_o = rate of steam produced from oil, lb/gal

FR_o = nominal oil firing rate, gal/hr

R_{sw} = rate of steam produced from solid waste, lb/ton

IR = rate of waste incineration, ton/hr

T_{sw} = average solid waste incineration time, hr/wk

T_o = average waste and fuel oil incineration time, hr/wk

FR_{om} = maximum oil firing rate, gal/hr

h_s = steam enthalpy, Btu/lb

Savings:

Annual savings = S_{HRI} (PC - ACS)

= 38,610 MBtu/hr (\$8.70/MBtu - \$6.05/MBtu)

= \$102,320/yr

where: H_{HRI} = energy from steam produced by the HRI, MBtu

PC = average cost of steam produced at the activity, \$/MBtu

ACS = average cost of HRI produced steam, \$/MBtu

CALCULATIONS FOR EXPECTED VALUES FOR MISSION RELIABILITY

The expected values for mission reliability were calculated based on Table 4 of the reliability analysis of the NAS Mayport HRI (Ref 5). The mission calculations were made using the predicted failure rates for each subsystem which was a part of the mission.

The failure rates and reliability for each subsystem are summarized in Table B-1. The mission reliabilities were obtained by multiplying together the reliability for each appropriate subsystem. The total failures were obtained by adding the appropriate subsystem failures. MTBF was calculated by dividing the mission time (6,240 hr/yr) by the total failures. These calculations are summarized in Table B-2.

Table B-1. Subsystem Data for Reliability Calculations

Subsystem	Failure Rate (failure/10^6 hr)	Mission Time (hr/yr)	Total Failures[a] (no./yr)	MTBF[b] (hr)	Reliability[b] (%)
Receiving (R)	234	6,240	1.5	4,274	97.2
Incineration[c] (I)	664	6,240	4.1	1,506	92.3
Oil Combustion[d] (OC)	331	6,240	2.1	3,021	96.1
Ash (A)	519	6,240	3.2	1,927	94.0
Boiler (B)	773	6,240	4.8	1,294	91.1

[a]Mission time/MTBF.

[b]Calculated from Appendix A equations.

[c]Normal solid waste incineration function.

[d]Function when fuel oil was used to produce steam. The only incinerator equipment utilized were the burner motors and the thermocouples for the incinerator.

Table B-2. Mission Reliabilities

Mission	Appropriate Subsystems[a]	Reliability[b] (%)	Total Failures[c] (no./yr)	MTBF[d] (hr)
1	R, I, A, B	77	14	446
2	R, I, A	84	9	693
3	OC, B	88	7	891

[a]These subsystems had to be operational for the mission to be accomplished. See Table B-1 for the code.

[b]For example, Mission 1 reliability:

$$0.972 \times 0.923 \times 0.940 \times 0.911 = 0.768 \times 100 = 77$$

[c]For example, Mission 1 total failures:

$$1.5 + 4.1 + 3.2 + 4.8 = 13.6 \text{ or } 14 \text{ failures/yr}$$

[d]For example, Mission 1 MBTF:

$$\text{Mission time/no. of failures} = 6{,}240 \text{ hr}/14 = 446 \text{ hr}$$

Appendix C

DATASHEETS

The tables (Tables 1 through 7)* in this appendix are copies of the sheets used for data gathering on operation and maintenance of the HRI at NS Mayport (Ref 9).

*These table numbers had not been changed to the numbering system of this document.

TABLE 1

Just Before Startup/Restart is Initiated.

PAGE NUMBER:____________

Item No.	Description	Reading	Remarks
1	DATE (Mo./Day/Yr)	________	
2	TIME HRI LIGHTED .... (Hrs.& Mts.; AM/PM)	________	
3	SOLID WASTE ACCUMULATOR READING .... (Before the first load has been delivered to the hopper)	________	
4	DID HRI START SATISFACTORILY ? .... (Yes/No) (If the answer is NO, go to a new sheet of Table 1. Number this new sheet in numerical order)	________	
5	I.D. FAN HOURMETER READING.........	________	
6	ELECTRICAL POWER METER READING	________	
7	STEAM FLOW TOTALIZER READING	________	
8	WASTE OIL, BURNER #1, TOTALIZER	________	
9	WASTE OIL, BURNER #2, TOTALIZER	________	
10	VIRGIN OIL, BURNER #1,TOTALIZER	________	
11	VIRGIN OIL, BURNER #2,TOTALIZER	________	
12	MAKEUP WATER FLOW TOTALIZER #1	________	
13	MAKEUP WATER FLOW TOTALIZER #2	________	
14	CONTINUOUS BLOWDOWN TOTALIZER	________	

NOTE: If you have comments and observations, please use a blank sheet of paper. Enter page number on it in numerical order as well as date it is prepared.

TABLE 2

During Operation Between Consecutive Shutdowns

PAGE NUMBER:____________

WEIGHT OF EMPTY FLYASH CONTAINER:____________lbs.

WEIGHT OF EMPTY REJECT CONTAINER:____________lbs.

WEIGHT OF EMPTY WET ASH CONTAINER:____________lbs.

Description	No.	Date	Weight	No.	Date	Weight
Loaded Flyash Container	1			2		
	3			4		
Loaded Reject Container	1			2		
	3			4		
	5			6		
	7			8		
	9			10		
	11			12		
Loaded Wet Ash Container	1			2		
	3			4		
	5			6		
	7			8		
	9			10		
	11			12		
	13			14		
	15			16		
	17			18		
	19			20		
	21			22		
	23			24		
	25			26		
	27			28		
	29			30		

NOTE: The last weight in each category is the gross weight of each container taken prior to disposal at landfill, after HRI shutdown.

TABLE 3

If during operation of the HRI the HRI was operated only on waste or virgin oil, and no solid waste was delivered to the hopper for any reason, then fill-in the following:

PAGE NUMBER:______________

TIME WHEN WASTE RAM WAS TURNED OFF: ____________
(Hr.& Mts.; AM/PM)

DATE WHEN WASTE RAM WAS TURNED OFF: ____________
(Mo./Day/Yr)

TIME WHEN WASTE RAM WAS TURNED ON: ____________
(Hr.& Mts; AM/PM)

DATE WHEN WASTE RAM WAS TURNED ON ____________
(Mo./Day/Yr)

COMMENTS

(Please feel free to note any unusual observation during operation of the HRI. If additional sheets are needed for the description, number the sheets in numerical order to permit CEL to ensure that the correct order is maintained.)

TABLE 4

After Each Shutdown (when I.D. Fan has been turned off)

PAGE NUMBER:__________

Number of Manshifts of contractor personnel used to operate the HRI, including front-end loader: __________

Number of Manhours of Public Works personnel used to operate or monitor the HRI while it is operating (if any):...................................... __________
(DO NOT INCLUDE TIME REQUIRED TO GATHER AND RECORD DATA FOR CEL'S LONG RANGE MONITORING OF THE HRI)

Item No.	Description	Reading
1.	DATE (Mo/Day/Yr)	______
2.	TIME SHUTDOWN (Hr. & Mts; AM/PM) .... (When the I.D. Fan is turned off)	______
3.	SOLID WASTE ACCUMULATOR READING	______
4.	I.D. FAN HOURMETER READING	______
5.	ELECTRICAL POWER METER READING	______
6.	STEAM FLOW TOTALIZER READING	______
7.	WASTE OIL, BURNER NO. 1 READING	______
8.	WASTE OIL, BURNER NO. 2 READING	______
9.	VIRGIN OIL, BURNER NO. 1 READING	______
10.	VIRGIN OIL, BURNER NO. 2 READING	______
11.	MAKEUP WATER FLOWMETER READING #1	______
12.	MAKEUP WATER FLOWMETER READING #2	______
13.	CONTINUOUS BLOWDOWN TOTALIZER READING	______

14. CONSUMABLE SUPPLIES USED DURING HRI OPERATION:

a) Amount of salt used:______lbs
b) Amount of PO_4 used:______
c) Amount of SO_3 used:______
d) Others (Describe) :______
:______
:______
:______
:______

15. CAUSE OF SHUTDOWN (Check ONE):

_____Routine Maintenance (Use Table 5)
_____Malfunction/component replacement (Use Table 6)
_____Other (Use Table 7)

TABLE 5

Shutdown for Scheduled Routine Maintenance

1. PAGE NUMBER:______________

2. TIME MAINTENANCE STARTED (Hrs. & Mts; AM/PM):_____________

3. MANHOURS OF CONTRACTOR PERSONNEL SPENT FOR ROUTINE MAINTENANCE (Hrs. & Mts.)......:_____________

4. MANHOURS OF PUBLIC WORKS PERSONNEL SPENT FOR ROUTINE MAINTENANCE (Hrs. & Mts.)......:_____________

5. TIME MAINTENANCE COMPLETED (Hrs. & Mts; AM/PM).......................:_____________

NOTES

1. Time spent during maintenance while the HRI is operating does not count.

2. If routine maintenance is carried out while the HRI is shut down because it is malfunctioning or if it requires component replacement, or it is shut down for any other reason, then this page MUST be filled out as if the shutdown was for routine maintenance. Of course, an additional sheet (Table 6 or Table 7) will precede this sheet under such circumstances.

3. Do NOT include time spent in meals, coffee breaks, waiting periods for supplies to arrive at the HRI, or any other reason not directly related to routine maintenance.

4. INCLUDE time spent cleaning the pit, hearth, or floors, etc.

COMMENTS:

(Describe specific major items of routine maintenance carried out. A short description like floors cleaned, pit cleaned, hearth cleaned, boiler tubes punched, boiler inspected, etc., will suffice)

TABLE 6

Shutdown Caused by Malfunction and/or A Need to Replace Component

1. PAGE NUMBER:__________

2. Explain clearly as to the nature of the malfunction. Use additional sheets if necessary, and number them in numerical order.

3. Cause of the breakdown, if it can be identified.

4. TIME REPAIR/COMPONENT REPLACEMENT STARTED:______________
   (Hrs. & Mts.)
5. DATE REPAIR/COMPONENT REPLACEMENT STARTED:______________
   (Day/Mo./Yr)
6. TIME REPAIR/COMPONENT REPLACEMENT COMPLETED:____________
   (Hrs. & Mts.)
7. DATE REPAIR/COMPONENT REPLACEMENT COMPLETED:____________
   (Day/Mo./Yr)
8. CONTRACTOR MANHOURS SPENT IN REPAIR/REPLACEMENT:______________

9. PUBLIC WORKS MANHOURS SPENT IN REPAIRS/REPLACEMENT:___________

10. LIST REPLACEMENT PARTS NEEDED AND COST OF EACH OF THESE PARTS, SEPARATELY, TO THE NEAREST DOLLAR.

11. LIST CONSUMABLES NEEDED AND THE COST OF EACH CONSUMABLE, SEPARATELY, TO THE NEAREST DOLLAR.

NOTES: 1) Do NOT include rest time or meal breaks in items 8 & 9.
2) In items 4-9, do NOT include time spent in procuring the replacement item, or cooling the HRI to permit working on it.

TABLE 7

Shutdown caused by Reasons Other than Routine Maintenance or Malfunction/Component Replacement

PAGE NUMBER:_______________

Describe the reason for the shutdown. For instance, steam not required by the base; solid waste not available; waste oil not available; virgin oil not available; shutdown because of holidays or vacation time for personnel; weekend shutdown, etc.

Was routine maintenance carried out while the facility was shut down? If it was, use Table 5 and complete the required information on the sheet. Number it in numerical order after this page, so that routine maintenance during idle time could be identified.

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MCRD SCE, San Diego CA

MILITARY SEALIFT COMMAND Washington DC
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NALF OINC, San Diego, CA
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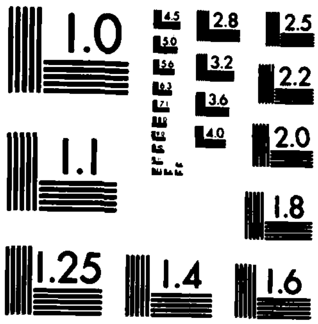

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